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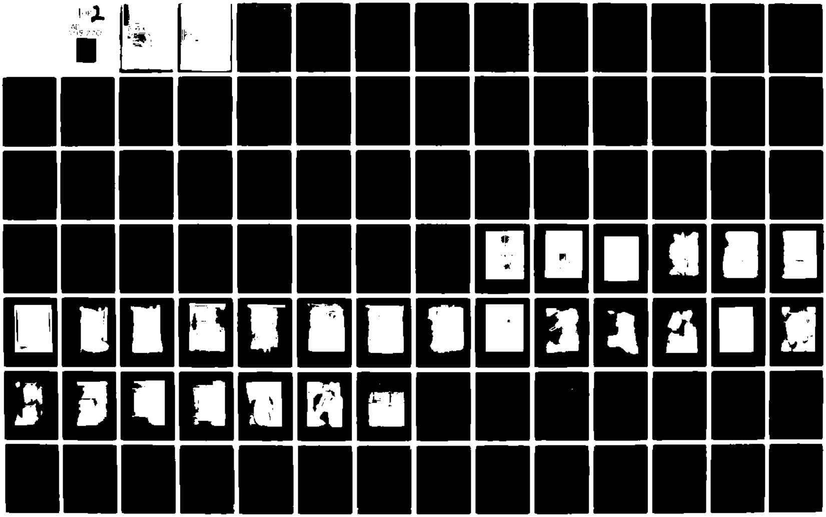

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A general purpose, two-axis, pointing-type payload has been built for use in the tethered balloon program at Holloman AFB. It is capable of carrying an experiment having directional requirements, and weighing up to 100 pounds. When attached to the flying lines of an aerodynamically shaped balloon and held by a single tether, it will keep an axis within the payload pointed toward a target light on the ground in a daylight operation with a precision of ± 0.75 degrees when elevated to 10,000 feet. Three modes of

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cont operation are possible, namely a stare mode, a search mode, and a pointing mode. In the stare mode the payload heading is set by commands from the ground, and the search feature permits an area surrounding the stare position to be scanned as a means of finding the target light. When the tracker finds the target the pointing axis in the payload will be continuously directed toward that target.

Features were included which allow the payload to be readily carried on the tines of a forklift during the launch operation. Only a single additional step is needed in the regularly used launch procedure, that being to arrest the let-up, anchor the system in a particular way, insert the payload, and continue the let-up in the normal way. Capability of the system was demonstrated in a successful test at Holloman in September 1981 while carrying a hitchhike experiment that measured IR transmissions through the atmosphere.

CONTENTS

1. GENERAL INFORMATION 9

1.1 Introduction 9
1.2 Features of the System 10
1.3 Launching 13

2. IDENTIFICATION OF SYSTEM COMPONENTS 13

2.1 Instrumentation Package and Contents 13
2.2 Mechanical Assembly 16
2.3 Tracker Head and Mounting 17
2.4 Balloon-To-Payload Coupling 17

3. PHOTOGRAPHS 18

4. WIRING INFORMATION 24

4.1 Rack Wiring 24
4.2 Relay Unit 25
4.3 Regulators 25
4.4 Mechanical Unit 27
4.5 Interface with Wire-Wrap Connections 30
4.6 Distribution of Voltages and Commons on Circuit Boards 30

5. CIRCUITS AND FUNCTIONS 31

5.1 Supplementary Information 31
5.2 Identifiers Used on Schematic Diagrams 31
5.3 Azimuth Control During Stare and Search 31

CONTENTS

5.4 Elevation Control During Stare and Search 34
5.5 Photomultiplier Tube 35
5.6 Spiral and Rosette Scans 35
5.7 Tracker Head Circuits 38
5.8 Acquisition Gate and Development of Error Signals 39
5.9 Controlling the Pulse Height 41
5.10 Pointing 41

6. NOTES ON USE 42
6.1 Target Light and Aperture Considerations 42
6.2 Choices and Adjustments 45

7. CONCLUSIONS 46

APPENDIX A: Plug Designations 89

APPENDIX B: Parts List for Electronic Circuit Boards 91

APPENDIX C: Commercial Components 105

ILLUSTRATIONS

1.	Complete Pointing System Being Moved to the Launch Area for a Test Flight on 16 September 1981.	48
2.	Payload Supported on the Tines of a Forklift, and Being Detached from the BST Vehicle Used for Transporting it to the Launch Site.	49
3.	Payload Being Attached to the Triplate While the Balloon System is Held by Two Anchor Lines.	50
4.	Complete Payload with Doors On.	51
5.	Payload with Left Door Removed Showing Mechanical Unit and Electronics Unit on Bottom Shelf.	52
6.	Paylead with Right Door Removed Showing Battery Pack.	53
7.	View Showing Internal Construction of Instrument Container.	54
8.	Left Side of Mechanical Assembly with Tracker-Head Hardware Removed.	55
9.	Right Side of Mechanical Assembly Showing Mounting Plate for Experiment.	56
10.	Rear View of Mechanical Assembly.	57
11.	Front View of Mechanical Assembly.	58
12.	Left Side of Mechanical Assembly with Instrument Package Raised to Show Regulator.	59

13. Left Side of Mechanical Assembly with Instrument Package Raised and Protective Barrier Removed. 60

14. View of Mechanical Assembly with Regulator and Protective Barrier Removed to Show Shaft Coupling, Torque Motor, and Gear Drive. 61

15. Hardware for Coupling Payload to Balloon, Showing Twin Anchor Lines, Bail-Attachment Fixtures, and Universal Coupling to Azimuth Shaft. 62

16. Coupling Hardware Showigg Bails that Attach to Flying Lines. 63

17. Dual 27-volt Regulator and Cirkitblock DC-DC Converter. 64

18. Power Amplifiers, Rear View of Relay Unit, and Filter Unit. 65

19. Electronics Unit in its Protective Cover. 66

20. Electronics Unit with Protective Cover Removed. 67

21. View Showing Circuit Boards Sandwiched Together. 68

22. Sandwiched Boards Hinged Open for Testing. 69

23. Upper View of Mechanical Unit. 70

24. View of Partially Open Mechanical Unit Showing Gearing. 71

25. Tracker Head in Place on Mounting Disk. 72

26. Photomultiplier and Optics Separated from Mounting Plate, with Lens Protection Removed, and Electronics Exposed at the Rear and Side. 73

27. Test Arrangement with Opened Circuit Boards Clamped to Shelf. 74

28. Rack Wiring and Interconnecting Cables. 75

29. Relay Unit. 76

30. Regulator. 77

31. Mechanical Unit. 78

32. Connections to Terminal Strips. 79

33. Distribution of Voltages and Commons. 80

34. Circuit Board 1, Part 1 of 2. 81

35. Circuit Board 1, Part 2 of 2. 82

36. Spiral and Rosette Scans. 83
37. Circuit Board 2. 84
38. Tracker Head Circuitry. 85
39. Circuit Board 3. 86
40. Circuit Board 4. 87

POINTING PAYLOAD FOR SINGLE TETHER BALLOONS

1. GENERAL INFORMATION

1.1 Introduction

Tethered balloons have been used extensively at Holloman Air Force Base to lift a variety of payloads to elevated positions, and to hold them there with relatively small horizontal displacements. Orientation of the payload in azimuth, and tilt as well, has been uncontrolled, the actual azimuth direction and the tilt being determined by the wind. Balloons used thus far have not provided a sheltered space where a stable platform or a pointing device could be located, such as is available in the T-Com system. It was the goal of this development to produce a pointing type payload that could be used at Holloman with existing balloons, and that could be launched with available equipment using current procedures. The new payload was intended to maintain continuous alignment between an axis in the payload and a position on the ground, making possible experiments that have directional features. Indeed, one such use was explored when the pointing system was first tested, that being to keep the optical axis of a balloon-

borne retroreflector directed toward an IR source on the ground, this to allow round-trip measurements of transmission through the intervening atmosphere. Whatever experiment is carried, it's presumed there will be a directional component that must be mounted on the pointing mechanism, and it's expected there will be associated facilities having no directional requirements that can be located elsewhere. Accordingly, provision has been made for carrying such equipment, including batteries, on shelves in an instrument package that is structurally integrated with the pointing mechanism.

1.2 Features of the System

Pointing is accomplished by placing a two-axis control system at the base of an aerodynamically shaped balloon where the necessary controlling torques can be developed. One axis is aligned with the tether by having the shaft be a series member of the tether line; it is nearly vertical, and is referred to as the azimuth axis. The second axis is normal to the first; it is essentially horizontal, and is referred to as the elevation axis. There is complete freedom of motion around the near-vertical azimuth axis, but only 120 degrees of movement is possible about the elevation axis. No slip rings are needed because the entire assembly spins around the azimuth shaft, and the limited elevation motion is accommodated by flex-type cables.

Command facilities and telemetry facilities are necessary for operating the system, and will share space in the instrument package. Command is needed for actuating switching and for controlling the attitude of the system, and telemetry is needed for monitoring system behavior. Provision has been made for telemetering with 10-bit accuracy the azimuth offset angle between the payload heading and the balloon heading, and there is a similar provision for telemetering the elevation angle as measured between the tether and the pointing axis of the tracker. Such angular data will be useful for inferring motions of the balloon.

The photograph in Figure 1 indicates how the control mechanism and the instrument package are arranged, with the instrumentation package at the top and the control mechanism below, all astride the

six-foot-long azimuth shaft that passes vertically through the system. At the bottom can be seen the optical pointing system mounted on an 18-inch disk, and to its left the cylindrical retroreflector that was used during the September 1981 test, both being coaligned and fastened to the short, 9-1/2 inches long, elevation shaft. Elements of the control mechanism were kept as close to the vertical shaft as possible to reduce wind forces on this unsymmetrical portion of the system. The near-vertical azimuth shaft passes through the center of the instrument package, and is kept in alignment with the mechanical mechanism below by having a third azimuth bearing at the top of the rigid instrument container. Provision was made for adding balance weights on both axes; two of medium size can be seen at the corners of the instrument container, and two of smaller size are visible on the plate which holds the optical assembly. Inside dimensions of the instrument package are 20" x 20" x 24". Weight of the pointing system, including instrumentation having to do with pointing, and hardware for coupling to the balloon, but without the 50-pound battery pack, and without either command or telemetry equipment, is 200 pounds. Provision was made for carrying the system on the tines of a forklift by adding stainless steel scuff pads that can be seen in the photograph below the instrument container.

Torque is applied to each axis by a 4 lb-ft torque motor acting through a nonslip belt drive having 5:1 ratio, making 20 lb-ft of torque available. Each torque motor is driven by its own power amplifier. Signals to the power amplifiers are derived differently, depending on the mode of operation, three modes being possible, a stare mode, a search mode, and a pointing mode. In the stare mode the azimuth heading is determined by a two-speed synchro system. Reference synchros are located in an auxiliary mechanism called the mechanical unit. Positons of these can be commanded to move in either direction, at either of two speeds. Companion synchros are geared to follow the angle between the azimuth heading of the payload and the balloon heading, the servo loop acting to make this angle match the setting of the reference synchros. Azimuth angles are not payload headings with respect to true north; they are payload

headings measured from the balloon heading, so are called azimuth offset angles. Command speeds for the reference synchros are approximately 2.6 degrees per second and 0.5 degrees per second.

Inputs to the elevation servo loop come from a reference pot in the mechanical unit and a pot on the payload that moves with the elevation angle. Position of the reference pot can be commanded to change in either direction at a single speed of 3.2 degrees per second. Again it should be noted that the elevation angle is not measured with respect to a true vertical, but is measured with respect to the azimuth shaft which is a part of the tether at its topmost position. Provided the vertical shaft is not tilted more than 15 degrees, elevation directions from the horizon down to nadir can be achieved with the 120 degrees of elevation movement, which means the payload can be commanded to point toward any ground target. Experience on the test flight showed that an operator stationed at the ground target can, by observing through a small spotting scope, determine when the system is approximately directed toward the ground target. That operator can call for commands to turn the payload generally toward the target, after which the system can search and find the target. When the search mode is enabled the package heading is moved systematically about the stare position, in both azimuth and elevation. In this mode the reference synchros are caused to sweep back and forth at a rate of 2.4 degrees per second. Size of the sweep can be adjusted up to a maximum of 38 degrees by changing a cam in the mechanical unit. During search the elevation angle changes in steps of about three-degree size, a step being taken at each reversal in the azimuth sweep. Each step produces an increase in the reference elevation angle until the last step has been taken, then the angle drops to the first-step level, which is set by the reference pot. A pattern of either four or eight steps can be selected. The third mode, and the intended mode of operation, is the tracking mode. When the pointing system is turned on, and the tracker acquires the ground target, signals for the power amplifiers that drive the torque motors are derived from the tracker, and the pointing axis is kept aligned with the ground target. Transfer from search mode to pointing mode causes an acquisition signal to appear

in the telemetering record. Also telemetered are monitors indicating the height of the photomultiplier pulse the voltage being applied to the photomultiplier, the azimuth error, and the elevation error, along with battery voltage, voltage from the reference pot, and voltage from the rack pot that follows the actual elevation angle. While tracking, the digital readouts of the azimuth and elevation angles show how the balloon heading and the tether tilt is changing.

To simplify launch preparations, voltage regulators are included which permit a fully-charged, 30-volt battery to be used without despiking. Scuff plates mentioned earlier allow the system to be lifted on the two tines of a forklift with no danger to the payload. This feature is particularly important during launch because the package is somewhat awkward, and the ends of the vertical shaft must be kept free for incorporation into the rigging.

1.3 Launching

Attention was given to the problem of launching the payload without appreciably altering the procedures currently employed at Holloman. A single additional step is added to the launch process, that being to stop the letup when the triplate is about 10 feet above the ground, and anchor it by means of two cables astride the sheave at ground zero. Thus anchored, the letup line can be slacked and disconnected, the payload can be attached to the special triplate, and the letup line can be attached to the bottom of the azimuth shaft. Finally, the two anchor lines can be slacked and uncoupled from the triplate, after which the system can be let up in the usual fashion.

2. IDENTIFICATION OF SYSTEM COMPONENTS

2.1 Instrumentation Package and Contents

A principal unit in the system is the instrument container, which not only provides space for housing instrumentation that needs protection, but adds rigidity to the structure as well. It has been fabricated partly from carefully dimensioned marine plywood and partly from aluminum that is interfaced with the wood in a manner to enhance the

strength of the wood. Shelves and bracing within the package are arranged to maximize package rigidity, bonding being done with waterproof glue. Basically the package is divided in the middle so there are six shelf spaces, three on either side of the two-part center partition. Four units that are part of the pointing system, and batteries for it, are located on the bottom shelf so these two spaces are not available for experimenters use. In the test flight, the top shelf on one side was used for AFGL telemetry and command equipment, so presumably this space is also dedicated. Three remaining shelves are available for experimenters use or for whatever other purpose may later appear, each space being 20" x 8" x 8". Aluminum angles running vertically along each corner are used for rigidly fastening the thermal package to the mechanical structure below. Special nuts have been inserted into the soft angles at three places along the front to hold doors, and at six locations along the side for balance weights. Such weights are needed for making final balance around the azimuth axis, some preliminary balance being achievable by judicious placing of heavy batteries within the container. In the test flight, for example, the fore-aft balance about the azimuth axis was made by carefully positioning, and anchoring, the 50-pound battery pack on its shelf, and the left-right balance was produced with two 10-pound brass weights, one at each of the two right-hand corners.

The 6-foot long azimuth shaft is held by two bearings in the mechanical assembly, one at the bottom and one at the upper end, but a third is needed at the top of the instrument container, otherwise the 25 mm stainless shaft could easily be bent. Rigidity of the instrument container, and the solid interfacing with the mechanical assembly, keeps the principal part of the azimuth shaft in proper alignment, but it is unsupported for a span of 12 inches above the top of the instrument container and 16 inches below the mechanical assembly. Caution should be exercised in handling the payload by the protruding shaft segments because it will bend if a force larger than about 200 pounds is applied in a direction normal to the shaft at its end. Reason for the extension at the top was to make room for the two special anchor cables

needed in the planned launch procedure. Extension at the bottom makes it impossible for the tether line below the shaft to interfere in any way with components on the payload.

Five components of the pointing system are housed in the instrument container, they are:

1. Battery Pack which consists of five BB/405 type batteries.
2. Relay Unit
3. Mechanical Unit
4. Electronics Unit
5. Filter Unit

In addition there is internal cabling which interconnects elements within the container and those outside. Free passageway for wiring is provided at either end of the shelves to permit interconnections from shelf to shelf or from any location within the container to elements outside. Protective wireways are included in the mechanical assembly to make it easy to pass cabling down through the wireways, and through flex cables, to the experiment on one end of the elevation shaft or to the photomultiplier assembly on the other.

Purpose of the relay unit is strictly to provide command-operated switching, which includes System On/Off, Photomultiplier On/Off, Search Mode On/Off, and a spare which was arranged for use by the experimenter when the system was flight-tested in September 1981. Presently the input to the extra relay is still connected to the command unit, but the output circuitry formerly present has been removed. Essentially the relay unit is an interface between the command, which has small-current capability with momentary switch closures, and the pointing system which requires isolated latching switch contacts capable of carrying larger currents.

Function of the mechanical unit is similar to the relay unit in that it is an interface between the command equipment and the system. Purpose of the mechanism is to allow command positioning of the reference synchros which determine the azimuth heading of the payload when in the stare mode, and to allow similar command positioning of the reference pot which determines the elevation angle in this mode. Dif-

ferential gearing and two cam-operated limit switches are used to produce the azimuth sweep during search, the size of the sweep being determined by the size of the actuating cam. Maximum possible sweep is 38 degrees, but usually a cam of roughly half this size would be chosen to give sweeps of 15 to 20 degrees. Cam-operated limit switches for the elevation reference pot are also used, these being set to make it impossible to drive the pot beyond appropriate limits. A 10-bit shaft encoder is included for telemetering information about the programmed azimuth offset angle. Also included in the mechanical unit is a small transformer that furnishes a stick-off voltage of 2.8 volts.

Much of the electronic circuitry for the pointing system is contained in the electronics unit, this being a principal item in the instrument package. Two low-pass filters, Model LMI-200, are used in the pointing system, but are physically too large to be fitted into the electronics unit, so they represent another separate item in the instrument package.

2.2 Mechanical Assembly

What is referred to as the mechanical assembly, also called the rack structure, is all of the hardware mechanism below the instrument package, including the items mounted on it, namely the torque motors, the power amplifiers, the inverter, the regulator, the synchros, the rack pot, two encoders, and the mounted tracker head located on one end of the elevation shaft. Structural part of the assembly is a long, narrow, rigid housing which holds the bearings for the two shafts, the long azimuth shaft that passes vertically through the structure, and the short elevation shaft that passes normally through it. Mounted on the structure are two 4 lb-ft torque motors acting through 5:1 gearing to drive the two shafts. Directly geared to the azimuth shaft is a pair of synchros, a 1X unit and a 36X unit, and a 10-bit shaft encoder to read out the azimuth offset angle. Synchros are companion to the pair in the mechanical unit, and are used in controlling the azimuth offset angle in both the stare and search modes. Coupled to the elevation axis is a pot whose output is repre-

sentative of the actual elevation angle, and a shaft encoder which also gives information about that angle. There is a 3:1 step-up in the gearing between the elevation axis and the shaft encoder associated with that axis, so a full revolution of the encoder shaft is associated with the 120 degrees of permissible change in elevation angle. A step-up of 2.88:1 is used in gearing the elevation shaft to the pot, this producing 346 degrees of pot rotation for the 120 degrees of permissible elevation change.

Two power amplifiers, and a 400 Hz inverter, needed for the synchro system, are mounted on the mechanical assembly as a means of providing the needed heat sink for these items. Also for heat sink reasons, the regulator is mounted on the rack structure.

2.3 Tracker Head and Mounting

Direction sensing when in the tracking mode is done with a 250 mm focal length lens that images the target light on a star tracker type photomultiplier tube, the latter being completely enclosed in a pressurized cylinder along with its associated high voltage power supply. This cylinder, the lens and its protective shield, and the 1/4-inch thick, 18-inch diameter aluminum plate on which the tracker head is mounted is referred to as the mounted tracker head, or as the tracker head assembly. Provision is made for tilting the axis of the tracker head with respect to the mounting plate, the fastening being hinged near one end of the photomultiplier housing, and the foot that supports the other end being adjustable in height. The plate is centered on the elevation shaft, and can be rotated with respect to that shaft to provide a second alignment adjustment. Numerous tapped holes have been added to the mounting plate to carry balance weights for the elevation axis. As previously stated, the tracker-head assembly is considered part of the mechanical assembly.

2.4 Balloon-To-Payload Coupling

Requirements for coupling the balloon and the payload included:

1. Easy attachment to the flying lines.
2. Self-alignment of the coupling with the two sets of flying lines.

3. Provision for attaching two anchor cables.

4. Universal joint to accommodate tilt of the azimuth shaft in any direction.

5. No backlash.

6. Quick insertion of payload, without tools or the need for safety ties.

These goals were met with a five-hole triplate having special fittings at each of the corners. Bails for gathering the two sets of flying lines are attached at the top corners with close-fitting, deep-throated, U-shaped fixtures that pivot on the coupling pins to conform to the angle between the two sets of lines. These fixtures stay with the triplate, the bails being separable from them. Another close fitting fixture at the bottom couples the triplate to the azimuth shaft in a manner to permit shaft tilt in any direction with respect to the plate. This fixture stays with the shaft, and is joined to the triplate during launch by means of a quick-insert pin. Two additional holes in the triplate allow the twin anchors to be attached when needed.

3. PHOTOGRAPHS

A better understanding of the payload configuration can be had by studying photographs in this section. The first three were taken during the flight test at HAFB on 16 September 1981, and the others are views showing various features of the system.

Figure 1

This was taken when the system was fully ready for flight, just after it arrived at the launch area. Antennas for command and for telemetering are visible at the top of the instrument container, which is closed and balanced. On the lower right can be seen the tracker head on its mounting disk, and to its left the cylindrical retroreflector. Payload was hanging from the boom of a BST vehicle.

Figure 2

View shows how the payload sits on the tines of a forklift, which in this case was supporting the payload while it was being uncoupled from the BST vehicle. During transport the bails at the top of the balloon-to-payload coupling served as a convenient point of attachment to the load carrier via short nylon lines.

Figure 3

When this photograph was taken the balloon had already been inflated and was being held by the twin anchor lines that extend down from the triplate to mooring points on either side of ground zero. How the flying lines on either side of the balloon are gathered by the bails at the top of the balloon-to-payload coupling is evident. At this stage of the launch the payload was being attached to the bottom hole in the triplate, subsequent steps being to connect the tether line to the bottom end of the vertical shaft, to slack and remove the twin anchor lines, and finally to raise the system by feeding the tether through the ground sheave.

Figures 4, 5, and 6

These views show the assembled system hanging in the laboratory. In Figure 4 the payload appears as it does in flight, with the doors on. Figure 5 is similar to Figure 4 except that the door has been removed to show the mechanical unit and the electronics unit sitting in their normal positions on the lower shelf. The two shelves above are available for experimenter instrumentation. In Figure 6 the payload is seen from the experiment side, but with no experiment attached to the lower mounting plate. Batteries for the pointing system occupy the bottom shelf, and can be positioned to the left or to the right to assist in balancing the system. Although the upper shelf is vacant in the photograph, it was used during the test flight for command and telemetry equipment, and presumably will be so used in future flights because interconnecting wiring is in place at that location.

Figure 7

View shows construction of the instrument package, with the azimuth shaft passing through. Holes of 1-5/8 inch diameter are at each end of each shelf, the one on the bottom shelf being visible. These holes and the two-part divider allow wiring to pass between levels, or from a compartment on one side of the package to the corresponding space on the other side. Bottom shelf on this side of the package carries the mechanical unit and the electronics unit. The shelf just above is not glued as all others are. Reason was to

accommodate a tall instrument, such as a gyrocompass, on this side of the package if such an arrangement ever is needed. Having the shelf removable has proved convenient when joining cables to the mechanical and the electronics units, the space there being very limited. These cables do not appear in the photograph because the picture was taken before the rack wiring was done.

Figures 8, 9, 10, and 11

Four sides of the mechanical assembly are shown when neither the tracker-head assembly nor the experiment is attached to the short horizontal shaft. Clearly visible at the center in Figure 8 is the elevation torque motor, with nonslip belting going downward to the elevation shaft. A second belt goes upward to the rack pot on the left and to the elevation shaft encoder on the right, both of which are behind the mounting plate and cannot be seen. The azimuth shaft encoder is visible near the top of the photograph, and protective wireways show on either side, with a cable emerging from the one on the left. Figure 9 shows the mounting plate for the experiment, with two radial arms to limit shaft rotation when they strike the cylindrical stop. How the power amplifiers are mounted on the framework for heat-sink reasons is clear, with the elevation power amplifier on the left and the azimuth power amplifier on the right. A rear view of the mechanical assembly is shown in Figure 10 with the mounting plate for the tracker-head assembly on the left, and that for the experiment on the right. Also visible in this view is the elevation torque motor, and the nonslip belting. How the elevation shaft encoder is held, and belt-driven, is evident at the upper left. Also visible near the top on the right is a small gear box with the synchros hanging below. A front view of the mechanical assembly is shown in Figure 11 with the experiment mounting plate on the left and that for the tracker-head assembly on the right. A 400 Hz inverter is directly above the azimuth power amplifier. How the elevation pot is mounted, and belt-driven, is visible in this view. Another view of the azimuth shaft encoder appears at the top right of the photograph.

Figures 12, 13, and 14

These photographs were taken when the instrument container was detached from the mechanical assembly, and slid up as far as possible along the azimuth shaft. How the regulator unit is incorporated into the system is shown in Figures 12 and 13. In the second of these photographs one of the protective barriers has been removed to reveal the azimuth torque motor, the large drive gear on the azimuth shaft, and the coupling which joins the two three-foot sections of azimuth shaft. A better view of the azimuth drive arrangement is shown in Figure 14 where more of the protective hardware has been removed. Belt drive on the azimuth shaft is visible, and below that another sizable gear couples shaft motion through a smaller gear to the gear box which drives the synchros. This same 4-inch, 300-tooth gear meshes with an identical gear to the left, partially visible in the picture, which in turn drives the azimuth shaft encoder hidden below. Both the 1X and the 36X synchros can be seen at the bottom of the small gear box.

Figures 15 and 16

Balloon-to-payload coupling is shown in Figures 15 and 16. In the first, the twin anchor lines are attached to the triplate, and the payload hangs below, being coupled to the azimuth shaft through a universal joint. A quick-connect pin is used to attach the universal coupling to the triplate. Shoulder bolt connection between the coupling and the shaft is normally not removed; the coupling stays with the payload. Hardware at the top of the triplate comes apart by removing the two bolts on either side, thus releasing the bails for gathering up the flying lines. Shoulder bolts passing through the triplate need not be removed when attaching bails to the flying lines; that hardware stays with the triplate. A better view of the bail structure is shown in Figure 16 where the hardware assembly has been isolated from the rest of the system.

Figure 17

A view of the dual-voltage regulator system is shown in Figure 17. Control circuitry is located at the center with the two main power transistors inserted in heat-sink blocks on either side. In

the rear on the left is an Abbott 5-volt, 4-amp, DC-DC converter, Model BL2D-5A, and on the right in the rear is a Cirkitblock DC-DC converter that generates 15-volt power and 5-volt power for the electronics circuits. All elements are mounted on a 1/4-inch thick aluminum plate.

Figure 18

Two power amplifiers, the back of the relay unit, and the filter unit are shown in Figure 18. A short cable on the amplifiers joins the manufacturer's input connector at the back of the unit to an added accessible connector, the latter making it possible to disconnect an amplifier without physically removing the unit. The seemingly open relay unit becomes closed and protected when the open face is mounted against an inner wall of the instrument container. Two LMI-200 filters are assembled together, with a single connector joining them to the electronics circuitry.

Figures 19, 20, 21, and 22

Much of the electronic circuitry is located in the electronics unit, which is built on four separate circuit boards as indicated in these photographs. Reason for using four was to fit the circuitry into the space available, the plan being to have both the mechanical unit and the electronics unit on one shelf. Views in Figures 19 and 20 show the completed assembly, the second with the protective cover removed. Figure 21 indicates how the two sandwiches can be separated, and supported on test legs. When working on the circuitry it's convenient to remove one circuit board, hinge it, and reattach the board as shown in Figure 22. With this arrangement both the wire-wrap sides, and the component sides, are accessible.

Figures 23 and 24

Two views of the mechanical unit show the upper surface of the gear box in Figure 23, and the gearing within in Figure 24. Located on the top plate are an encoder; two reference synchros; a reference pot; two motors for driving the azimuth gear train at two different speeds; a motor for driving the azimuth gear train during search; a motor for driving the reference pot; a pair of cam-operated switches to limit movement of the elevation pot; and a cam segment with two switches to reverse the azimuth sweep, a reversal occurring when the

cam reaches either end of its travel. A degree counter, and a box containing eight relays for controlling the motors, are a part of the unit, the degree counter being useful for determining rates of motion, and for measuring the azimuth sweep. In Figure 24 the sides of the gear box have been removed to expose gearing below. In this view the degree counter and the switching relays are easily seen, as is a small transformer at the end of the relay box, this to provide a stick-off voltage for the azimuth servo system.

Figures 25 and 26

Views of the tracker-head assembly are shown in Figures 25 and 26. In the first, the parts are completely assembled on the 18-inch diameter mounting disk. Holes for balance weights are clearly visible. Coalignment of the experiment axis with the tracker-head axis is done by moving the tracker head, limited alignment normal to the plate being achieved by tilting the tracker head. It is hinged at the front support, and held at the back by an adjustable-length foot, both features being visible in Figure 25. The large disk pivots on the elevation shaft so unlimited alignment is possible in that direction. Slotted holes, visible in Figure 26, permit movement from one hole to the next in the heavy mounting plate on the end of the elevation shaft. In Figure 26, the plate at the rear of the photomultiplier assembly, and the one on the side as well, have been removed to show where circuitry associated with this assembly is located. Also, the protective housing for the 250 mm lens has been removed, and the whole assembly has been separated from the mounting disk.

Figure 27

A test arrangement that was convenient while developing the system is shown in Figure 27. Circuit boards are hinged open and clamped to an external shelf, connections to rack wiring being made through extension cables. Shelf is supported on aluminum angles fastened to the front and the back sides of the instrument container, using holes available for balance weights. A small push-button test box for simulating the commands is shown on the shelf at the left.

4. WIRING INFORMATION

Material in this section includes the rack wiring which interconnects all components, the switching relays that can be actuated by command, the regulation of voltages needed for operating the system, a circuit diagram of the mechanical unit, and diagrams showing how voltages are fed to and distributed throughout circuit boards in the electronics unit.

4.1 Rack Wiring

Different parts of the system are considerably separated, necessitating appreciable wire lengths and a total of 27 connectors. The photomultiplier and certain of its associated circuits must be mounted on the elevation axis, well away from the electronics unit located in the instrument package. Synchros for following the azimuth offset angle, and the rack pot which follows the elevation angle, must be positioned on the mechanical mechanism. For heat sink reasons the inverter and the voltage regulators are also mounted on that structure. There is physical separation within the instrument package too, the mechanical unit and the electronics unit being on the opposite side from the battery, and the telemetry and command equipment being two shelves above. What is referred to as rack wiring is largely concealed to keep it protected and out of the way; it is diagrammed in Figure 28. Plastic tubing has been used to protect wiring in those places where the circuitry branches out to one or another of the various connectors. Figure 28 indicates that wiring goes directly to the inverter, the rack pot, and the rack synchros, so those units are a part of the rack-wiring circuitry. Also shown on Figure 28 are cables needed for interconnecting different units. Cables shown with the two power amplifiers are mounted on the amplifier units, and are needed because the normal amplifier connections emerge from the back so are not conveniently accessible. Addition of the short extensions makes it possible to easily disconnect the amplifiers whenever necessary without removing them from the rack to make the manufacturer's connectors available. An extension also was used with the 10-bit encoder located

in the mechanical unit to make it impossible to exchange the 19-pin connector belonging to the electronics unit with the 19-pin connector going to the encoder. Use of the extension also facilitates inserting the plugs into the mechanical unit.

Although the schematic of the rack wiring can be used to follow the electrical connections between units, this isn't usually necessary because circuit diagrams include in parentheses at each pin position the plug number and pin designation of the unit to which that pin is connected.

4.2 Relay Unit

Part of the interfacing between the command receiver and the pointing system is accomplished with the relay unit. Circuit closures within the receiver operate relays in the relay unit which have isolated switch contacts of suitable power handling capability. Wiring of the relay unit is diagrammed in Figure 29, which shows three small relays with 2-ampere contact rating, and a large relay with 10-ampere contact rating. Power from the battery comes in at J2, is switched at "System On" by Relay K1, and is passed out to the dual regulator. Separate contacts are used for carrying currents to the two separate regulator systems. Relay K2 is used to switch the photomultiplier circuitry on and off by passing the 27-volt output from one regulator through the contacts of K2 to the photomultiplier, this action being referred to as pointing on/off. Relay K3 is used to enable the search mode by command, but another relay contact is in series so it too must be closed for search to occur. The second relay contact is closed until pointing begins, then it opens to disable search during pointing. A fourth relay, K4, was included as a spare command-operated switch in case one is needed. Wiring is in place for commanding the relay, but outputs at pins W, X, Y on J3 are not connected to any rack wiring. Contacts of K4 were used during the test flight to make switched power available to a heater in the retroreflector, but this wiring has since been removed.

4.3 Regulators

It was assumed that BB405 type silver batteries would be used

for powering the payload, and it was planned that five such batteries would constitute the main power source. Output from such a battery pack starts at 37.5 volts when fully charged and drops progressively to the normal plateau of 30 volts, this plateau being reached after almost 20 per cent of the battery capacity has been expended. Although the troublesome spike can be removed by dumping 15 or 20 per cent of the energy prior to using the battery, this is a chore to do, and reduces the battery available for flight. Unless despiking is done, the options are to subject all circuitry to over-voltage for a considerable period of time, or to incorporate regulators to keep the voltage being used at a proper level at all times. Limiting the voltage is absolutely necessary because the inverter and the Cirkitblock DC-DC converter cannot accept more than 30 volts. Threat of excess voltage, and the despiking problem as well, was eliminated by building the regulator system diagrammed in Figure 30. There are two separate regulators, each set to deliver 27 volts. The upper one supplies the needs of the inverter and of the mechanical unit, and it furnishes power to the Cirkitblock DC-DC converter, a commercial unit having two 5-volt, 1-ampere outputs, and two 15-volt, 300 milliampere outputs. The latter two are joined to provide ± 15-volt power to the amplifiers used in the electronic circuitry. One of the 5-volt supplies is used in the pointing system, and its negative side is joined to the center tap of the ± 15-volt supply to form what is referred to as the analog common. No connection exists in the regulator between the power common and the analog common, but they are both connected to the rack at the power amplifiers. The second 5-volt supply is used only for the digital shaft encoders, and its negative side, which is referred to as the digital common, is also connected to telemetry at pin 31, plug number 21. Presumably there is a connection between the digital common and the circuitry used for command and telemetry, but there is no connection between this common and the circuitry associated with pointing. A second 27-volt regulator shown at the bottom of Figure 30 supplies power to the photomultiplier, a relay in the electronics unit, and to the two power amplifiers.

An unusual feature of the regulator circuits is the inclusion of a 5-volt Abbott DC-DC converter to raise the voltage on the μA723 units, and on Q1 and Q3 as well, above the battery voltage being supplied to Q2 and Q4. This allows a regulated output of 27 volts from a 30-volt battery, even when a bit low. Input to the Abbott unit is taken from the output of Regulator 1 because it cannot accept voltage from a fully charged battery. A starting feature is necessary, which is provided by Diode D1. After starting the diode has reverse polarity and draws no current. Resistors R7 and R15 limit the current that may be supplied by the Abbott to either circuit. Each regulator output is current limited at 12 amperes, and the circuit is safe if the battery voltage is too low for the regulators to function. A voltage divider, R17 and R18, allows a sample of the battery voltage to be delivered to the telemetry circuitry on pin 1, Plug 20.

4.4 Mechanical Unit

Like the relay unit, the mechanical unit is an interface between the command receiver and the payload; it establishes the commanded reference angles, both the azimuth offset and the elevation, and provides the search feature.. A schematic diagram of the circuit is shown in Figure 31. Essential items are the two 400 Hz synchro transformers, and the elevation pot, all shown at the lower left portion of the diagram. Stators of the synchros are connected to the stators of the synchro transmitters on the rack that follow the azimuth offset angle between the balloon heading and the payload heading. Outputs from the synchro transformers in the mechanical unit are sent to the electronic circuitry for processing to develop an input to the azimuth power amplifier and torque motor for driving the payload to a position where the electrical angles of the two sets of synchros correspond. A small 2.8-volt stick-off voltage is added to the output of the 1X synchro to make it impossible for the system to lock on a reverse heading. Output from the elevation reference pot is likewise fed to the electronics unit where this negative voltage is added to negative step voltage and to the posi-

tive voltage from the rack pot to develop a total which is processed and fed to the elevation power amplifier and torque motor for driving the elevation axis to a position where the voltage from the rack pot matches the total of the voltage from the reference pot and the steps.

Positioning of the reference synchros is done by Motors M3 or M4, and positioning of the reference pot is by Motor M1. Relays K1 through K6 are actuated by maintaining command closure on the appropriate channels. Relays K1 and K2 cause Motor M3 to move the synchro gearing in either direction at the fast speed of 2.6 degrees per second. Similarly M4 is actuated by Relays K3 and K4 to move the synchros in either direction at the slow speed of 0.45 degrees per second.

Positioning of the reference pot is done by commanding Relays K5 and K6 to either increase or decrease the elevation setting. In this case, however, there are limit switches, S3 and S4, which when suitably set prevent the pot from moving beyond its limits. Cam settings can be chosen to restrict the elevation movement to any desired range of angles. Normally the decrease limit, governed by S4, would be set for an elevation angle of -15 degrees, but it may be set at any angle below that which is needed for the experiment. Upper limit, determined by S3, should be set in conjunction with the search steps. Setting for the cam actuating S3 cannot exceed that which during search keeps the radial arms from hitting the mechanical stop, the test being made after the reference pot has been commanded to its maximum position. At the lowest elevation step, the elevation angle is the reference pot value, and the steps add elevation angle from there.

Relays K7 and K8 are arranged to cause Motor M2 to sweep between limits determined by the size of the cam that actuates Switches S1 and S2. Grounding pin a on J9, which is what happens when search enable has been commanded and the system is not pointing, causes Motor M2 to sweep back and forth through a 38-degree angle if a full size cam is used. Usually a smaller cam would be employed to restrict the sweep, and shorten the time to complete a search pattern.

There is a second relay in parallel with K8, designated K2 on

Figure 32, which initiates the elevation stepping. Since K2 is closed when the azimuth angle is increasing during sweep, and open when the azimuth angle is decreasing, the contacts of the parallel relay change state and can initiate an elevation step at each reversal of Motor M2, which is precisely the desired pattern. Resulting search pattern has the azimuth angle sweep at a rate of 2.4 degrees per second through an angle set by the cam size, with the elevation increasing in three-degree steps at each azimuth reversal. Logic in the electronics causes elevation steps to be taken until the maximum level is reached, after which the stepping returns to the lowest level. Four steps should be enough, but eight can be selected by adding a link between T-12 and T-13 on Circuit Board 1.

Gearing within the mechanical unit is fixed and should never need attention. Zero backlash gears are used between the two synchros, with the 36X unit moving 36 times faster than the 1X unit. Gear ratio between the slow motor, M4, and the 1X synchro is 2880, and the ratio between fast motor, M3, and the 1X synchro is 1080. Motors M3 and M4 drive the gear train through a differential which allows either motor to set the rate. Both motors can be on together if simultaneous commands are issued, then the speed of the gear train is either the sum or the difference of the individual rates. Gear ratio between the search motor M2 and the 1X synchro is 525. A differential is also involved in this gearing so Motors M3 or M4 can operate simultaneously with Motor M2. Gear ratio between Motor M1 and the elevation pot is 6.33. Rates of moving either the synchros or the pots can be changed by substituting other motors for those presently employed, though it is believed the motors now used produce desirable and completely acceptable rates.

In the lower right corner of Figure 31 is shown the reference shaft encoder, which is coupled to the 1X synchro with 1:1 gearing. A full 360 degrees of azimuth change is associated with the full 1024 bit count on the shaft encoder. Output from the reference shaft encoder corresponds to the azimuth offset angle only during stare and search; after transfer to the pointing mode it has no relationship to the actual payload heading. But it is wise to keep its read-

ing reasonably aligned with that of the azimuth encoder on the rack by issuing suitable commands. Reason is that if pointing is momentarily interrupted search will be initiated at approximately the correct payload heading. The elevation situation is similar. Again it's advisable to continually update the reference pot to keep it at a suitable angle for searching in case tracking is interrupted.

4.5 Interface with Wire-Wrap Connections

Circuits in the electronics unit were built up on four circuit boards using wire-wrap construction. Interfacing with solder-type wiring used elsewhere is done within the electronics unit at terminal strips, one being associated with each circuit board. Figure 32 shows how the solder-type wiring extends from Connectors J5 and J6 to the circuit boards, with Connector J5 joining to Terminal Strip 1 and 2, and Connector J6 joining with Terminal Strips 3 and 4. Relay K2, mentioned in the preceding section, is a part of the solder-type circuitry, as is Relay K1 that stops search when the system is pointing. Wiring depicted in Figure 32 extends the rack wiring to the circuit boards in the electronics unit where wire-wrap construction begins.

4.6 Distribution of Voltages and Commons on Circuit Boards

How the supply voltages and analog commons are distributed throughout the wire-wrap construction is spelled out in Figure 33. Pins on Sockets A and B on each board are solder connected with buss wire to make voltages available at numerous wire-wrap terminals. Pins 1 through 8 on Socket B are paralleled to provide eight wire-wrap distribution points for +15 volts, and pins 9 through 16 are paralleled to provide a similar number of distribution points for -15 volts. Socket A is divided in a different way with more pins being used for analog commons than for +5 volts power. What circuit positions are fed from each buss point, and how the chain connections are made, is also shown on the diagram. Interconnections of other terminals on the circuit boards are shown on the circuit diagram associated with individual boards.

5. CIRCUITS AND FUNCTIONS

5.1 Supplementary Information

Although the diagrams presented so far, and those yet to be dealt with, give information about components, additional information has been included in Appendices A, B. and C. The first tabulates connector numbers, and identifies exactly what types are used; the second presents the complete parts list for each of the four circuit boards in the electronics unit; Appendix C lists numerous of the commercial components used in the system.

5.2 Identifiers Used on Schematic Diagrams

Circuits in the electronics unit are built up on four circuit boards, numbered 1 through 4. Sockets on each board are identified by letters, the sequence A through Z being used on each board, with double letters when necessary, so the board number, as well as the socket letter, must be specified when referring to a particular component. Individual pins on a socket are identified by a letter followed by a dash and the pin number, such as G-7, which means Socket G, pin 7. Headers carrying circuit elements, including resistors, capacitors, and diodes, are inserted in many of the sockets. Physical location of each circuit element is shown on schematic circuit diagrams by placing at each end of each circuit element the socket letter and pin number to which that end is attached. Individual resistors, and other elements as well, are identified as R1, R2, C5, D2, etc., but these must not be confused with notations like R-2 and C-5 which signify Socket R, pin 2, and Socket C, pin 5.

5.3 Azimuth Control During Stare and Search

Circuitry for controlling the azimuth heading in the stare mode is located on Circuit Board 1, and is shown schematically on Figure 34. A 400 Hz signal from the 1X control transformer in the mechani-

cal unit comes in at pin H of Connector J5, and a similar 400 Hz signal from the 36X synchro arrives at pin J of that connector. Effective voltage at pin H is 1 volt per degree of azimuth error when the error angle is small. For larger angles the correct value is 57.3 sin(error angle), so it reaches a maximum of 57.3 effective volts at 90 degrees. Error angle is the difference between the electrical angle of the reference synchro and that of the synchro on the rack. Since the rack synchro is geared to follow the offset angle between the payload heading and that of the balloon, the real meaning of azimuth error is the amount by which the actual payload heading differs from the reference heading. Error voltage at pin J varies in a similar fashion, but because of the 36:1 gearing between synchros it passes through its full cycle with only a 10-degree change in azimuth error angle. For small error angles the voltage at pin J is 36 volts per degree of actual azimuth error.

Each voltage is reduced by a factor of about ten before being demodulated, that being done by synchronously rectifying the error voltages delivered at pins K-1 and R-1 on the diagram. Pursuing for the moment only the 1X channel, the output from the follower is delivered directly to pin L-7, and to pin L-6 with inverted phase. Switches in component L reverse state at each zero crossing of the 400 Hz reference signal coming in on pin T of J5 because the switch is controlled by the LM111 comparator identified as component E. A full-wave rectified signal is developed at pin L-5, with a polarity depending on the phase of the error voltage with respect to the reference voltage. Much of the variable part of the rectified voltage is filtered out by the circuit that follows to produce a near d-c output at pin K-8, the magnitude of which follows the error angle, with the polarity depending on whether the error is positive or negative, meaning the azimuth offset angle is to the right or to the left of the position specified by the 1X reference synchro in the mechanical unit. Lag-lead-lead-lag compensation is introduced by the circuitry associated with the next two operational amplifiers, and finally an amplitude adjustment is made to produce a voltage at pin AA-1 suitable for delivery to the azimuth power amplifier. It goes to S-8 and, if

switch S is in the state shown, it passes through to pin A of J7 and on through another switch on Board 4 before reaching the azimuth power amplifier, assuming that acquisition by the tracker has not occurred, in which case the switch on Board 4 connects the azimuth amplifier to the tracker circuitry.

Demodulation and compensation of the 36X signal is done in the same manner to produce an output at AA-7, this being delivered to pin 9 of the switch labeled S. Whether switch contact S-10 is connected to the 1X output or to the 36X output depends on the magnitude of the error, with transfer being made to the 36X circuit when the 1X error falls below approximately 3 degrees. Then the 36X synchro is in the correct one of its 36 angular segments, so driving the power amplifier with the 36X signal will bring the payload to the position where the signals from both synchros are zero together. Circuitry at the upper right portion of the diagram senses when the azimuth error falls below the 3-degree value. A sample of the 1X error voltage is taken from pin L-7 and passed to Diode D1 and Capacitor C3 to produce a positive voltage of irregular waveform which is fed through R4 to an integrator that also receives a steady negative input through R5. Circuit constants have been chosen to make the output of the integrator at pin F-1 saturate with negative output when the error angles are large, and to have transfer to positive saturation when the error angle is below 3 degrees. Output from Transistor Q1 is near 5 volts until the error angle falls below 3 degrees, then the transistor is turned on and the voltage falls to zero, at which time Switch Arm S-10 transfers to the 36X channel, and the azimuth power amplifier is controlled by the 36X synchro. Another solid state switch, component Z, is used to short the inputs to the follower circuits designated BB and CC when acquisition by the optical tracker has taken place. Reason is to keep the large capacitors in the low frequency lag circuits discharged and ready for use when control is transferred back to the synchro system.

Operation of the circuitry just described is the same when in the search mode as when in the stare mode, the only difference being that in the search mode the reference synchros are swept back and

forth instead of remaining fixed at one position, and the azimuth torque motor must move the payload heading back and forth to keep the rack synchros aligned with the changing reference synchros.

5.4 Elevation Control During Stare and Search

Circuitry for controlling the elevation axis during stare and search is also located on Board 1, the schematic diagram being shown on Figure 35. Inputs to this circuit come from the elevation pot on the rack, and from the reference pot in the mechanical unit, these appearing respectively at pins V and U on Connector J5. After passing through followers the inputs are summed to produce a total at W-8. Since positive voltage is applied to the rack pot and negative voltage is applied to the reference pot the sum represents the difference between the actual elevation angle and the reference value. Output from W-8 is passed through compensation circuitry to produce a difference signal at AA-8 which is passed to the elevation power amplifier through a switch on Board 4. It reaches the power amplifier when operating in the stare and search modes, but the switch on Board 4 transfers control to the pointing circuitry when acquisition by the optical tracker is made. Negative signal from the reference pot is inverted to produce a positive output at W-7 which goes to the telemetry circuitry via pin F on Connector J22. Positive voltage coming from the rack pot is also sent to telemetry via pin B on Connector J22.

How elevation search is accomplished is shown at the top of the schematic diagram. Relay K2, which is effectively in parallel with Relay K8 in the mechanical unit, is actuated when search is causing the azimuth angle to increase, and relaxes when search is causing the azimuth angle to decrease. Location of K2 is on the frame that holds Board 2, and was included in the wiring shown on Figure 32. Bouncing of the relay contacts is eliminated by a pair of cross-connected, 2-input NAND gates in component EE. Square-wave output from pin EE-4 is used to actuate one of the switches in component GG, and it's also used to clock the J/K flip flops connected for binary counting in component FF. Outputs at FF-6 and FF-8 used to actuate two other

switches in component GG. The arrangement causes a change of state of the lower switch in component GG at each reversal of the azimuth sweep, a change of state of the second switch up at alternate reversals of the azimuth sweep, and a change of state of the third switch up at each fourth reversal of the azimuth sweep. Common output from the switches feeds an 8-level staircase current to the summing amplifier at W-9, adding to the currents coming through R50 and R51 from the rack pot and the reference pot. Size of the current steps can be adjusted by changing R48. As presently connected R48 has been chosen to produce elevation steps of about 3 degrees, which is somewhat less than the 3 1/2-degree field-of-view of the tracker head, so there is some overlap in the search pattern. Provision has been made for using either four or eight steps. A jumper placed on Header T of Board 1, between pins T-12 and T-13, selects the eight-step pattern, and if this link is omitted a four-step pattern ensues.

5.5 Photomultiplier Tube

Subsequent sections will indicate how the photomultiplier tube is used in the pointing system. Tube design is such that only those electrons emitted from a small spot on the photocathode enter the multiplier section to produce an output at the anode. Spot diameter is 0.014 inches, this being known as the IEPD, or "instantaneous effective photocathode diameter". If there are no currents in the deflection yoke the small spot at the center of the 0.75 inch diameter photocathode is the one that causes an output from the multiplier. Other spots will initiate the multiplier output if appropriate currents are passed through the deflection yoke. Coils in the yoke have magnetic axes at right angles, and spot displacement is proportional to current, so the magnitudes of the two coil currents represent the displacement of the active spot from the tube center in rectangular coordinates.

5.6 Spiral and Rosette Scans

If two sinusoidal currents of equal magnitude and 90 degrees out

of phase are passed through the deflection coils the resultant magnetic field within the yoke has constant magnitude and a direction that rotates at a uniform rate of one revolution per cycle. Such a field causes the IEPD to travel around the face of the tube in a circle centered on the tube face, the diameter of the circle being proportional to the magnitude of the two equal currents. In the search mode, the magnetic vector is caused to spin at 200 revolutions per second, and its magnitude is varied sinusoidally at 1 Hz rate. This causes the face of the tube to be fully scanned in spiral fashion four times each second. If the target light is imaged somewhere on the photocathode there will be a pulse from the photomultiplier each time the IEPD passes over the target image. A feature of the spiral scan caused by having the magnitude vary sinusoidally is that successive turns of the spiral are much closer together at the outside edge of the tube face than at the center. This fact is illustrated in the upper part of Figure 36.

The rosette scan is like the spiral scan in that the magnetic field within the yoke spins at 200 turns per second, but in this case its magnitude is varying sinusoidally at 800 Hz rate. Path of the IEPD then is an eight-petal figure like that shown on the lower part of Figure 36, with a petal for each half cycle of magnitude change. Solid lines in the diagram indicate the path followed by the center of the IEPD, and the dotted circle is a reminder that a spot, and not a point, is following the rosette path. Adjacent petals are not developed in sequence. If petals are numbered from 1 through 8 in a counterclockwise direction, then the order of development is 1, 6, 3, 8, 5, 2, 7, 4.

How the scans are produced is shown on Figure 37, the circuit diagram for Board 2. There are three quadrant oscillators on the left, namely E, F, and G, operating respectively at 1 Hz, 200 Hz, and 800 Hz. Oscillator F develops a 200 Hz sine wave at pin 1 and a 200 Hz cosine wave of the same 10-volt peak magnitude at pin 7. Sine-wave output is fed to Multipliers H and J, and cosine output is fed to Multipliers K and L. A second input to Multipliers J and L is the 1 Hz sine wave from E-1. Output from Multiplier J is a 200 Hz sine

wave and output from Multiplier L is a 200 Hz cosine wave, and the magnitudes of both change sinusoidally at a 1 Hz rate. These are exactly the waveforms needed to produce the spiral scan previously described. They are fed through the switch designated M when that switch is in the state shown. Output at M-10 passes through a follower and a three-input summing amplifier to a coil driver which has the BB 3329/03 booster designated V forcing a current through the U-D coil to make the drop across R14 equal to the output of the summing amplifier at N-8. An identical circuit in the lower portion of the diagram uses the 200 Hz cosine output from Multiplier L to force current through the L-R coil. Scanning continues as long as Switch M remains in the state shown, which is the scan state.

A different situation exists when Switches M and P are actuated, and they change state together because both are controlled by the same voltage. Then the inputs to the summing amplifiers come from Multipliers H and K. As previously stated these multipliers receive respectively the 200 Hz sine and cosine signals, and they also receive the 800 Hz sine signal. Output from Multipliers H and K have the waveforms needed to force rosette currents through the deflection coils. Rosette currents immediately appear when M and P change state, but the spiral-scan currents present at the instant of switching do not instantly die away. Reason is that the voltages on Capacitors C7 and C8 are discharged through 5.1 megohm Resistors R8 and R15, and the time constant for the decay is 2.4 seconds. Result is that the rosette scan is initially centered at the point on the tube face where the IEPD was located at the instant switching occurred. Switches M and P are arranged to be actuated when the first photomultiplier pulse appears, so the rosette scan is initially centered on the target image, and the photomultiplier starts outputting 1600 pulses per second. Actual position of the rosette center at any instant also depends on the third inputs to the summing amplifiers, those made through R9 and R16. Inputs are zero until Switches M and P change state, and the rosette scan is initiated, then voltates are applied to R9 and R16 to keep the rosette centered on the target image, a feature that will appear subsequently.

Size of the spiral scan covers the face of the tube, but the rosette scan is only 7.5 per cent as big, this being determined by the ratio of R11 to R10 and R18 to R17. This fact is not suggested in Figure 34 where the two scans appear to be of equal magnitude, but the illustration was intended only to show the type of the path followed by the IEPD in the two scans.

Also shown on Figure 37 are the gates used later to split the photomultiplier pulses for integration. These sense when spot movements due to the 200 Hz currents in the deflection coils change from up to down, and from left to right. Output from Comparator Z is high when the 200 Hz sine wave is positive and low when it is negative. This is the up-down gate that goes to Board 3 via pin H on Connector J7 for use in processing the photomultiplier signal. Likewise the output from Comparator AA is high when the 200 Hz cosine wave is positive and low when negative; it is the L-R gate needed on Board 3.

5.7 Tracker Head Circuits

Circuitry associated with the tracker head is shown on Figure 38. Both the photomultiplier tube and the high voltage power supply are contained within a pressurized housing, allowing operation at any altitude. Separate magnetic shields surround the power supply and the tube as indicated in the diagram. Resistors for dividing the high voltage among the various dynodes are soldered to the tube pins, so no socket is involved. A 180-volt zener is used at the cathode end of the divider to keep the voltage constant on that section when the voltage from the high voltage power supply is varied. Components for the high voltage power supply were taken from a commercial unit and repackaged to fit into the housing, the commercial unit being that shown in Appendix C. Located at the back of the housing structure, but not pressurized, is the regulator circuitry, shown at the left side of the diagram; it's used for reducing the 27-volt power from the main regulator to a value suitable for driving the high voltage power supply. Rated output from the high voltage supply is 1800 volts when the input is 20 volts, but a smaller input voltage is generally used.

Input to the supply can be reduced, but not raised, by applying a suitable control voltage at Connector J11, pin D. When no control is acting, the input can be adjusted using the 2K potentiometer. Circuit values have been chosen to permit adjustment between 11.5 and 19.0 volts, so any pot setting is safe. Upper limit can be raised to 20 volts if needed by paralleling the 24K resistor with a 1 megohm resistor. How the photomultiplier control operates will appear later.

Circuitry shown at the right-hand side of the diagram is enclosed in a nonpressurized section at the side of the tracker head. Output from the photomultiplier is developed across the 1 megohm resistor. Direct-current component of the voltage across the resistor is blocked by the small capacitor, and the higher frequency components are fed to the FET type operational amplifier. Break frequency of the resistor-capacitor combination is 20 Hz, which eliminates some of the undesired fluctuations. Limiter circuitry associated with the amplifier protects it from damage by very high voltage pulses that can be developed by the photomultiplier. Output from the first operational amplifier is fed through another resistor-capacitor branch, also having a break frequency of 20 Hz, to a line driver capable of delivering the pulses to the electronics unit through the long wiring that intervenes. Also included in this section is a DC-DC converter, BB 510A, to provide isolated ± 15 volts for the operational amplifiers. A voltage divider at the lower right-hand corner monitors the actual input voltage being delivered to the high voltage power supply, and sends it to telemetering.

5.8 Acquisition Gate and Development of Error Signals

When the first photomultiplier pulse is developed during the spiral scan it shows up at pin J of Connector J6 on Board 3, as indicated on Figure 39. If the negative pulse causes the voltage at C-4 to exceed the -1.5-volt threshold at C-3, the comparator output at C-9 goes high for the time the pulse is above the threshold. This output constitutes a pulse-duration gate to actuate Switch K. It is also fed through Diodes D2 and D3, and Resistor R6, to the fast inte-

grator designated D. Time constants are such that the integrator output goes from a small positive value to a negative value in about five microseconds, a time span considerably shorter than the pulse duration. Comparator E therefore changes state early in the pulse period to initiate a positive gate at E-9, called the acquisition gate. Unlike the pulse-duration gate at C-9, which ends when the photomultiplier pulse ends, the acquisition gate lingers because the charging current through R7 is only 3 microamperes. If additional photomultiplier pulses come in rapid succession after the first, the voltage at E-9 will remain high and maintain the acquisition gate. When present, the gate is fed out through Follower U to initiate switching elsewhere, and to telemetering for monitoring acquisition. It is also inverted by Component X to actuate Switch Y. Normally open contacts of Switch Y are held closed until the acquisition gate appears, then they open to allow Integrators Z and S to operate. Inputs to the integrators are zero except when the pulse-duration gate is high, and Switch K is actuated. Switch L, actuated by the U-D gate, determines which polarity Integrator Z receives at any instant. If the target image is at the exact spot where the rosette scan is centered, Integrator Z will accumulate nothing because it receives one polarity for the first half of the pulse-duration gate and the other polarity for the second half. But if the target image is slightly above or below the center of the rosette scan the pulses are unequally split and the integrator develops an output. In like manner, Integrator S accumulates an output only when the target image is to the left or the right of the center position of the rosette scan.

Outputs from the integrators are passed through low-pass filters to the summing amplifiers shown on Figure 37. Outputs from the two filters keep the rosette centered on the target image, wherever it may be on the tube face, and they provide a two-coordinate measure of the displacement of the target image from the center of the tube face. These are error signals that can be used to steer the payload to the heading that places the target image at the center of the photocathode. They are also scaled down to produce monitors at U-14

and Y-10 which go to telemetering Connector P20 by different routes. Range of both monitors is $\pm$ 2.5 volts, and the sensitivity of both is 1.4 volts per degree of error, or about 0.7 degrees per volt on the monitor, which means specifications are met if the monitor voltages do not exceed one volt.

5.9 Controlling the Pulse Height

Although circuitry on the right side of Figure 38 will not be damaged by large voltages developed across the anode resistor, it is still desirable to keep the anode voltage below 15 volts peak-to-peak. This is done by the circuitry shown at the top of Figure 39. Pulses coming through Capacitor C1 have ground reference restored by clamping Diode D1, so the signal going to C-4, and up to Resistor R11, is a negative pulse with respect to common of about 15-volt height, this being the maximum that Comparator C can accept. It's inverted by the operational amplifier above, and reduced to about 11-volt size at U-8. Diode D5 and Capacitor C4 operate as a peak detector to produce a near DC voltage at U-7 equal to the peak pulse height. This is divided by Resistors R15 and R16, and filtered by Capacitor C5 to produce the peak-pulse monitor going to telemetering at pin F of Connector J6. Voltage at U-7 is also fed to the integrator at the upper right in Figure 39. Integrator output at U-14 is approximately +5 volts when no pulses are present, or when the pulse height does not exceed the 9-volt rating of Zener Z1. If pulses are larger, the zener conducts and a positive current is fed to the integrator to reduce its positive output. Voltage at U-14 is passed through pin H of Connector J6 to the regulator circuit shown on Figure 38; it is the photomultiplier control. When the control voltage falls below the nominal voltage at the base of the 2N3704 transistor, roughly 4 volts, the diode there begins to conduct and drag the base voltage down, thus reducing the input to the high voltage power supply. This lowers the pulse height, and the positive component of current going into the integrator on Figure 39. Constants have been chosen to make equilibrium occur at a pulse height of about 13 volts.

5.10 Pointing

It was mentioned in Section 5.8 that voltages developed by the electronic tracker for keeping the rosette centered on the target image are suitable for steering the payload to the heading where the target image is at the center of the photocathode. This is the heading sought by the tracker, the one that has the tracker axis pointed toward the target light. Error signals that were fed to the summers in Figure 37 are also fed to Circuit Board 4, which is diagrammed in Figure 40. Elevation error signal comes in on pin C of Connector J23, is passed through lag-lead-lead-lag compensation circuitry, and after magnitude adjustment is fed to pin C-8. In a similar way the azimuth error signal arriving at pin E of Connector J23 is processed and delivered to C-7. If the acquisition gate exists, Switch C is actuated and the processed error signals are passed out to the power amplifiers for controlling the payload heading. Switch C is the one previously referred to that connects the power amplifiers to the stare/search signals until acquisition occurs. Pointing involves having the torque motors continually drive the payload to the position where the error signals are small. Switch P keeps the large capacitors in the low-frequency lag circuits discharged and ready for use when acquisition takes place.

6. NOTES ON USE

6.1 Target Light and Aperture Considerations

An important precaution is that the illumination on the photocathode be kept below 5 footcandles as stipulated in the specification sheets for the tube. This calls for cautious handling, and it particularly means that the system should never be allowed to lock on the sun as a target. Keeping the illumination below 5 footcandles means keeping the light entering the lens below 5.3 microlumens because the area of the IEPD is 1.07×10^{-6} square feet. Response of the tube to 5 microlumens would be enormous. At 1800 volts on the tube the data indicate responsivity of about 1000 amperes/lumen, or 1000 microamperes/microlumen, so 5.3 microlumens would pro-

duce an anode current of 5300 microamperes, and a voltage across the 1 megohm anode resistor of 5300 volts. Obviously it couldn't happen. For the circuitry to function the light level must be kept well below the 5 footcandle limit, or the voltage applied to the tube must be lowered. Peak voltage across the anode resistor at the instant of acquisition should be no more than 150 volts, then the pulse-height servo will adjust the pulse height to 13 volts. But a first-instant pulse much in excess of 150 volts will make the system acquire poorly, or not at all. If 19 volts is initially applied to the high voltage power supply, giving a tube voltage of about 1700 volts, the responsivity is indicated to be about 520 microamperes per microlumen, so the luminous flux must be held to 0.29 microlumens to keep the initial pulse below 150 volts. It is suggested that the luminous flux be kept below 0.2 microlumens, and that the initial input to the high voltage power supply be set at 19 volts.

Diameter of the aperture in inches needed to limit the flux to 0.2 microlumen is related to the candlepower of the target light and the range in feet by the equation

$$D = 0.006 \times R/\sqrt{CP} \ .$$

For example, if CP = 100,000 and R - 2500 feet, the diameter should be equal to or less than 0.047 inches.

Brightness of the background is another consideration because it too illuminates the photocathode, the relationship being that the illumination in footcandles is given by 0.0026 times the background brightness in footlamberts times the square of the aperture diameter in inches. Brightness of the desert under noonday sun is probably less than 2000 footlamberts, and it surely shouldn't be as much as 3000 footlamberts. But the brightness of a sunlit cloud could reach 10,000 footlamberts. If the higher value is used the relationship gives a maximum diameter of 0.44 inches for 5 footcandles on the photocathode. This represents a lens setting of f/22 on the 250 mm lens, so care should be taken to keep the lens stopped down to f/22, or preferably to the limit, which is f/32. Then the tube is protected from background light when the small apertures required for proper operation are being changed.

Output from the photomultiplier is produced by both the background illumination and by the target light, so it's helpful to have a relationship giving the ratio of the two signals. This ratio is independent of the aperture used, but it does depend on the focal length of the lens. For the 250 mm lens, the ratio of target signal to background signal is approximately $2 \times 10^6 \times CP/(B \times R^2)$, where CP is candlepower of the target, B is brightness of the background in footlamberts, and R is range in feet. A target having 25,000 candlepower at a range of 2500 feet with a background of 10,000 footlamberts, gives a ratio of 0.8. This was approximately the situation encountered when aligning the system for the test flight. During the flight, when B was lower, the ratio of target signal to background signal was larger. Best performance will be achieved by choosing a target light that gives a ratio of target signal to background signal of at least 5.

In using the system it is always necessary to carefully select the aperture, particularly when the target is close. A selection of apertures having diameters ranging from 0.016 inches to 0.180 inches is supplied. Diameters were chosen to make the aperture area increase by a factor of two for each succeeding step. Area ratio of the largest aperture to the smallest one is 128.

Assuming 19 volts is initially applied to the high voltage power supply, an aperture should be selected to keep the initial pulse height below 150 volts by keeping the target flux entering the lens down to 0.2 microlumens as previously stated. If this selection is made, the pulse-height servo will not push the input voltage to the high voltage power supply below 14 volts. If it goes lower a smaller aperture should be chosen. Ratio of responsivity at 19 volts to that at 14 volts is 27.5. Values of responsivity plotted in Appendix D are closely approximated by the useful expression

$$\log(\text{microamperes/microlumen}) = 0.00359(\text{PM voltage} - 1200) + 0.886.$$

Although the target light used in the field test is supplied with the system, a better one should be procured. Advertised candlepower for the unit was 360,000, but the actual value is roughly 25,000. The unit used in the test was battery operated, and very convenient.

In seeking a replacement it is important to find one that operates on direct current, otherwise there will be 60 Hz fluctuations that will affect the pointing system.

6.2 Choices and Adjustments

Prior to use two decisions must be made about the search pattern. Width of the azimuth sweep is determined by a cam in the mechanical unit, the maximum possible sweep being 38 degrees. Smaller cams will permit the field to be searched in a shorter time, and should usually be adequate. Either four or eight elevation steps are possible, so a choice must be made prior to launch, and the link inserted if eight steps are selected.

Limit switches in the mechanical unit must be set to allow the desired elevation angles to be reached. Setting the upper limit must be done in conjunction with the elevation steps to avoid having the radial arm hit the stop at the top. Setting for the lower limit is usually that which just keeps the other radial arm from hitting the stop.

Focusing the lens is a simple matter, but must always be attended to. Spacing between the lens and the photomultiplier has been adjusted to validate the range readings on the lens, so all that is needed is to set the focus to the correct range value.

Prior to flight attention should be given to telemetered voltage levels and zero readings. Both the azimuth reference encoder and the actual azimuth encoder have been set at zero when the payload heading aligns with the balloon heading, which means they read the correct azimuth offset angle, but this should be confirmed prior to flight, and if the intended situation doesn't exist, it should be corrected or the actual zero reading should be recorded. Other telemetered data, including the limits for the elevation reference pot, the limits for the rack pot, the step voltages, the pulse height monitor, the battery monitor, and the acquisition gate, should be looked at and recorded.

A pot on the back of the photomultiplier tube adjusts the voltage applied to the high voltage power supply when pulses are absent. An input voltage to the high voltage power supply of 19 volts was used

in the flight test, and has been extensively used in the laboratory testing. It produces a voltage of about 1700 volts, which is probably appropriate for most situations.

A threshold voltage of-1.5 volts exists at C-3 on Circuit Board 4. This has worked well in laboratory testing, but a higher value may prove more satisfactory for outdoor situations, and the possible need to change the threshold should be kept in mind.

It is necessary to balance the load around both axes. Balance is partially achieved on the elevation axis by careful positioning of the experiment, and it is finished by adding weights to the mounting plate for the tracker head, using the holes provided. Balance about the azimuth axis can be partially achieved by positioning the 50-pound battery associated with the pointing system, and blocking it in place, and it's finished by adding weights as needed at the corners of the instrument package. Procedure for balancing the azimuth axis is to hang the payload on the tines of a forklift using the balloon-to payload hardware to provide a rigid support. An indicator, like a straight wire, can be taped to the bottom of the shaft and extended to a position near the floor where a piece of cross-section paper is placed as a reference. By observing how the indicator shifts when the payload heading is reversed, first along one direction and then along an orthogonal direction, it's easy to sense what weight adjustments are needed. Correct balance, of course, is achieved when the indicator stays in one position for all payload headings.

7. CONCLUSIONS

Objectives of the development were to produce a pointing type payload that could carry an experiment weighing 100 pounds and point toward a ground target in a daylight operation with a precision of $\pm$ 0.75 degrees when elevated to 10,000 feet on presently available aerodynamically shaped balloons held by a single tether and launched with existing equipment using current procedures. The payload produced meets or exceeds the stated goals. Capability and launchability of the system was demonstrated in a field test before it

was completely finished. Since that time a number of important and significant features have been added, and the system has been extensively refined through laboratory testing. The finished version has all of the features originally planned, and fulfills all of the objectives of the development.

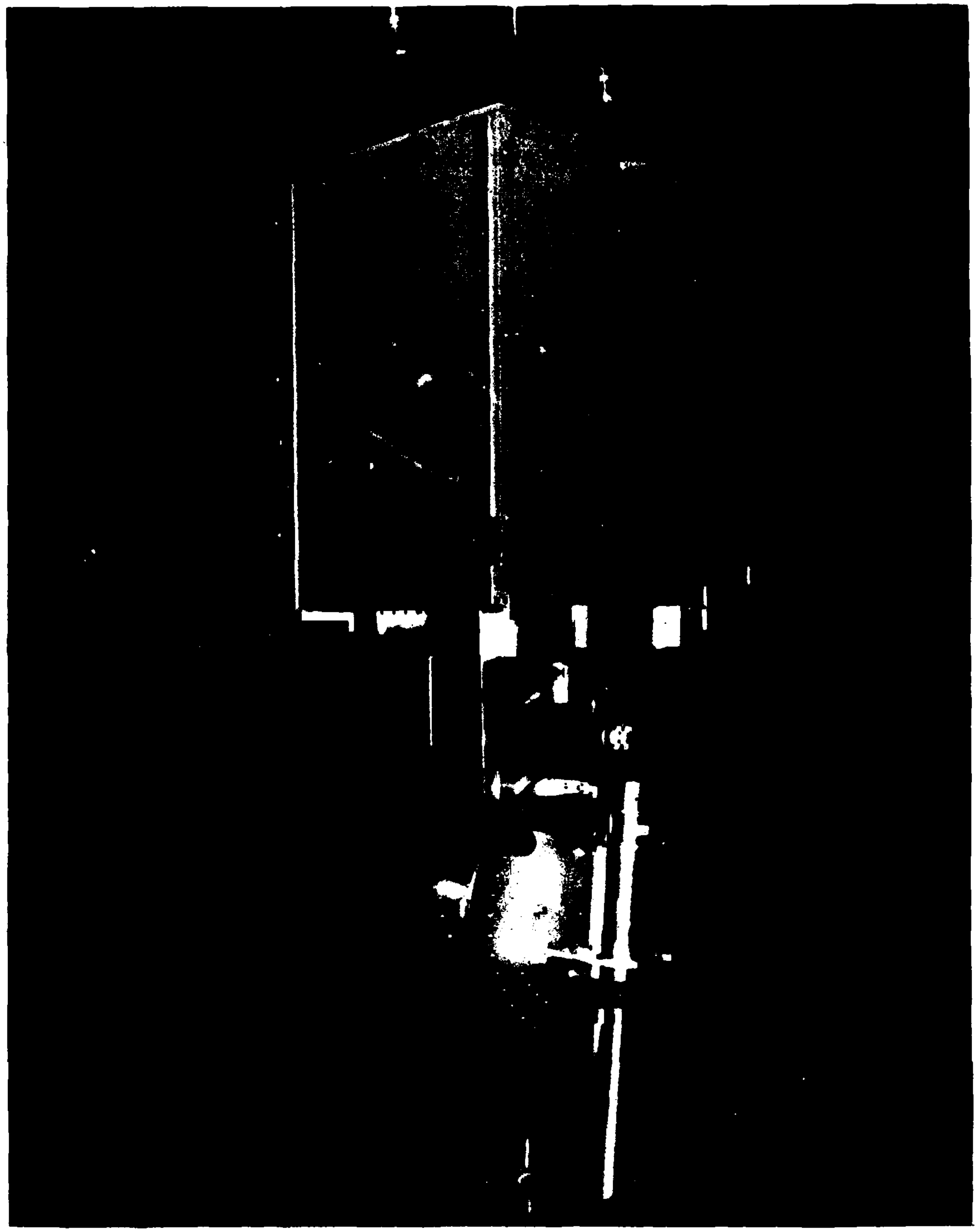


Figure 1. Complete Pointing System Being Moved to the Launch Area for a Test Flight on 16 September 1981.

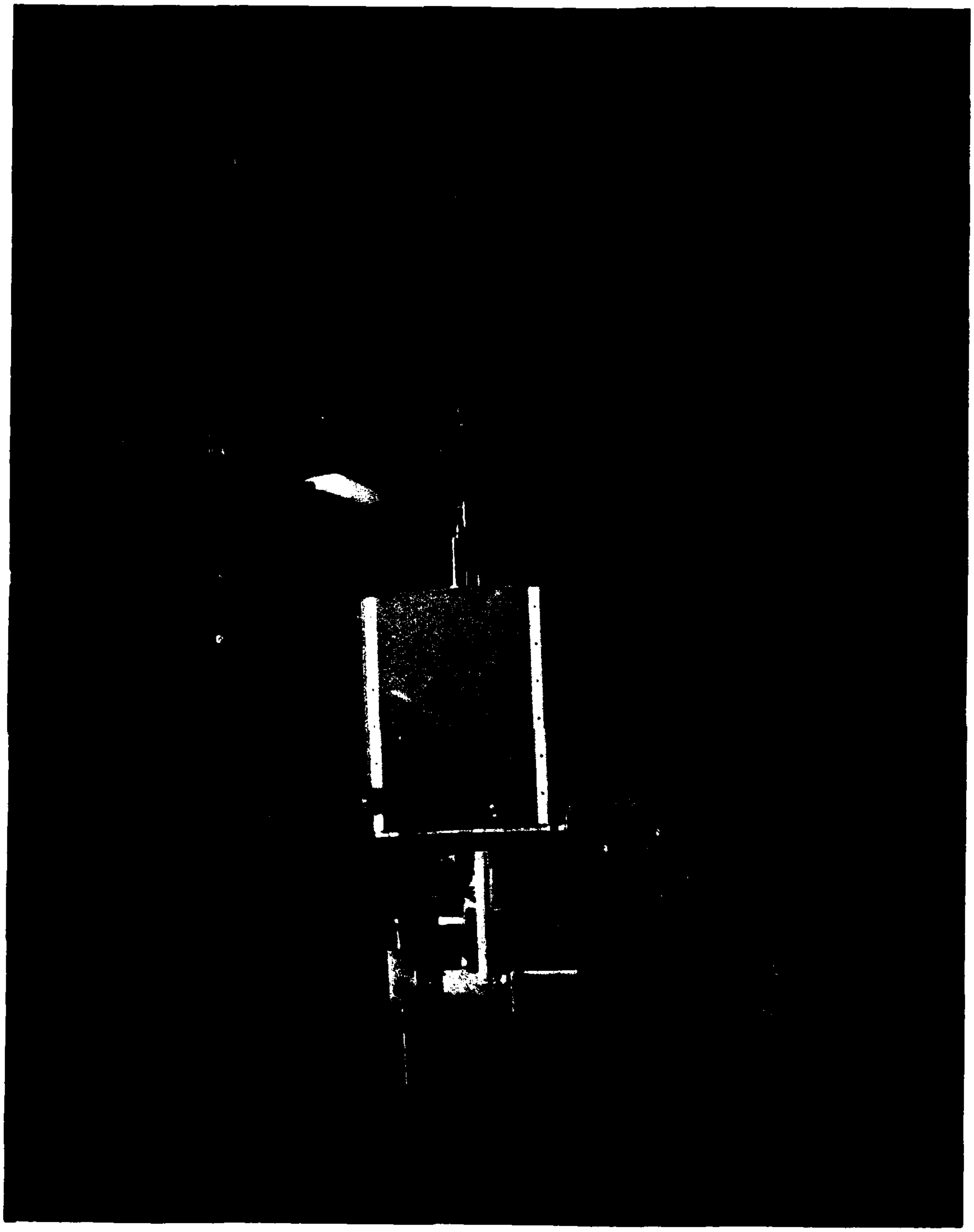


Figure 2. Payload Supported on the Tines of a Forklift, and Being Detached from the BST Vehicle Used for Transporting it to the Launch Site.

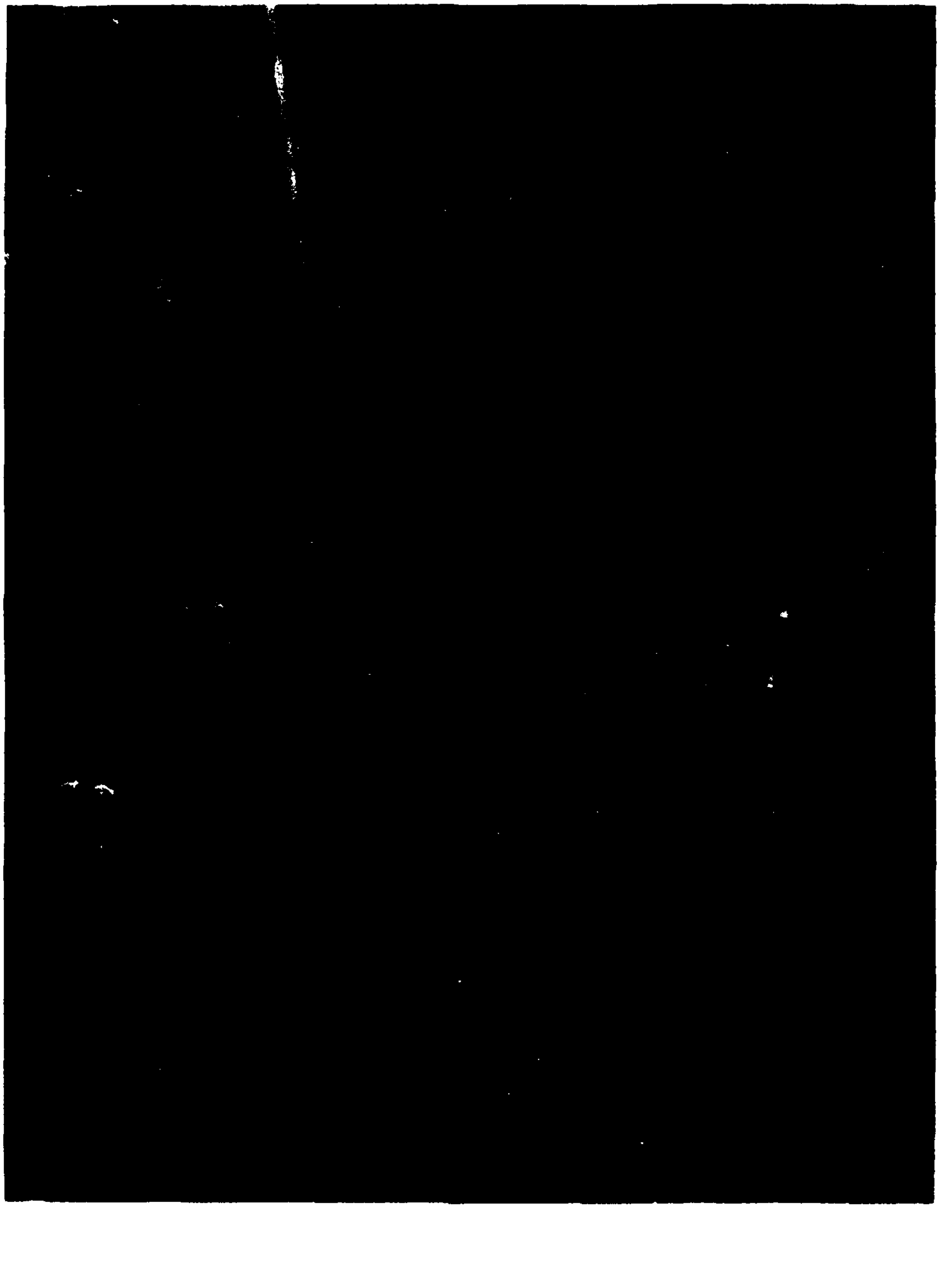


Figure 3. Payload Being Attached to the Triplate While the Balloon System is Held by Two Anchor Lines.

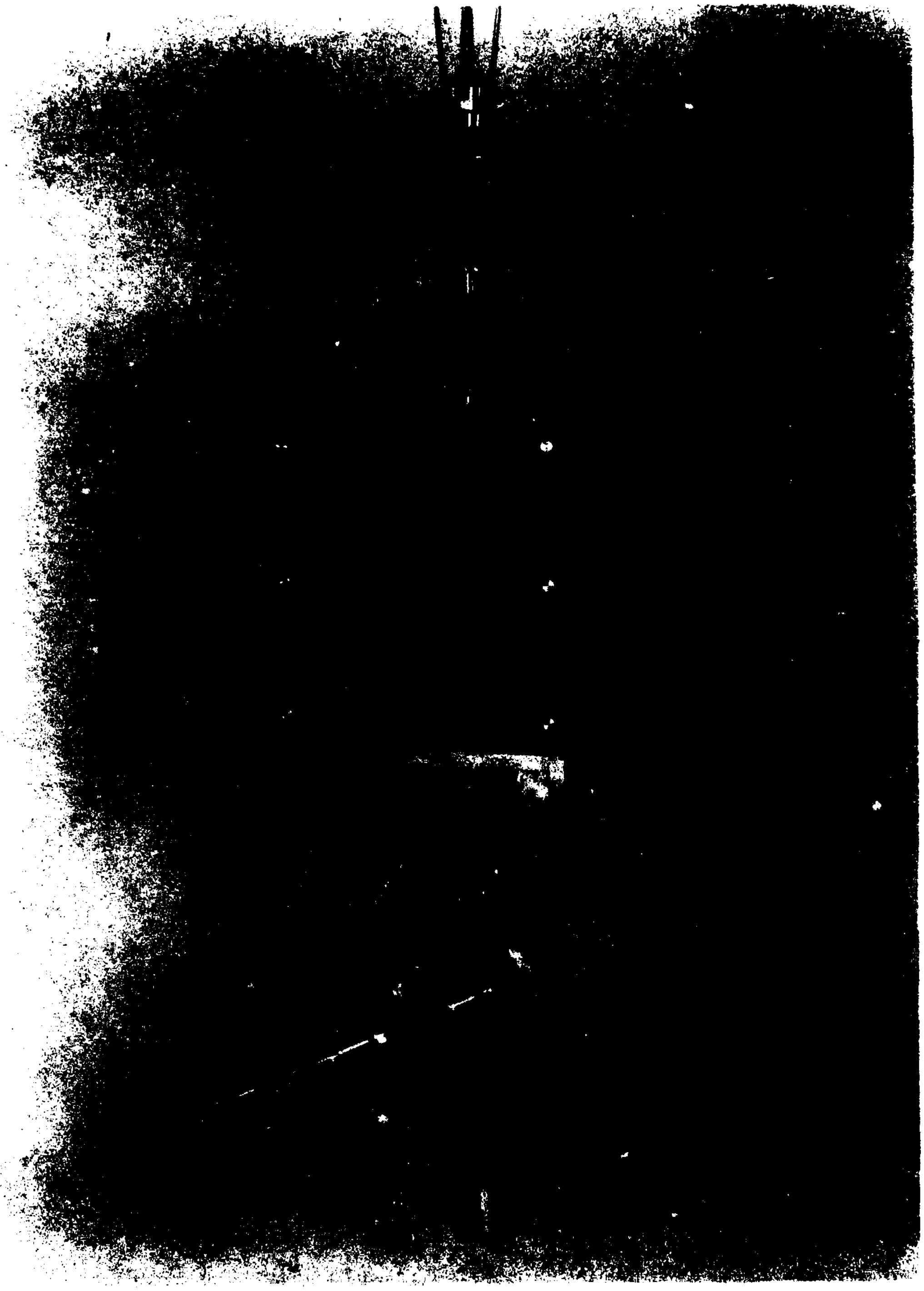


Figure 4. Complete Payload With Doors On.

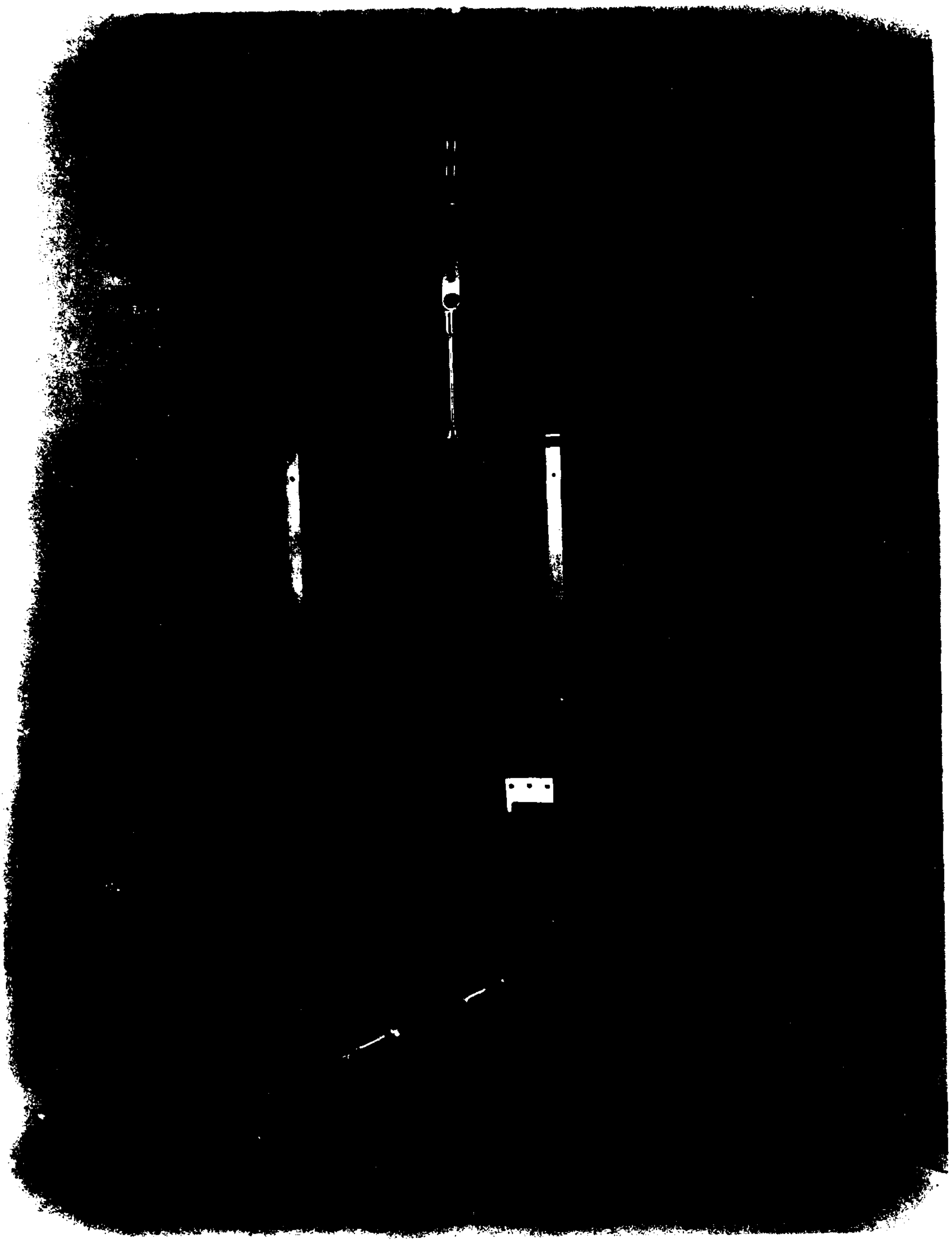


Figure 5. Payload with Left Door Removed Showing Mechanical Unit and Electronics Unit on Bottom Shelf.

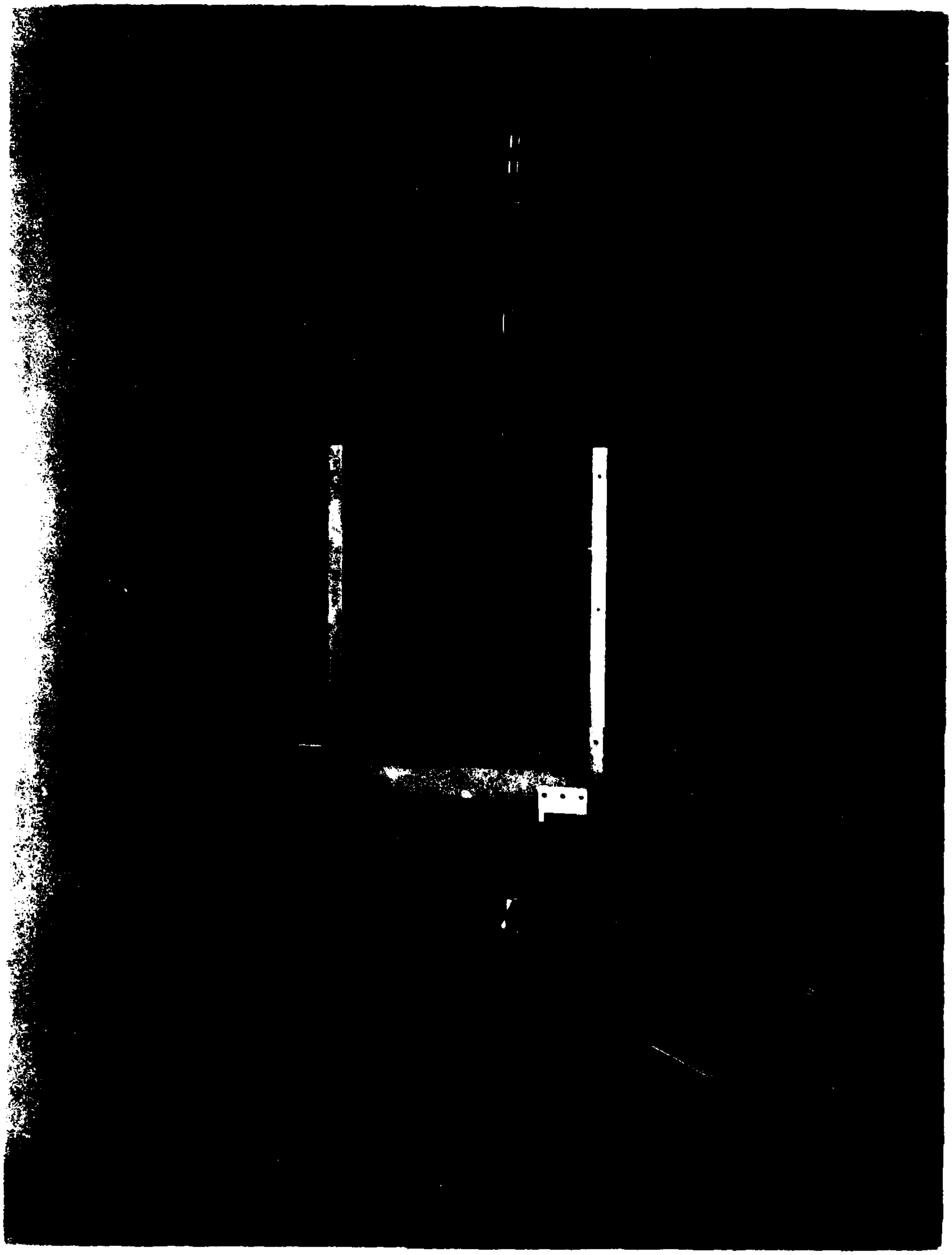


Figure 6. Payload with Right Door Removed Showing Battery Pack.

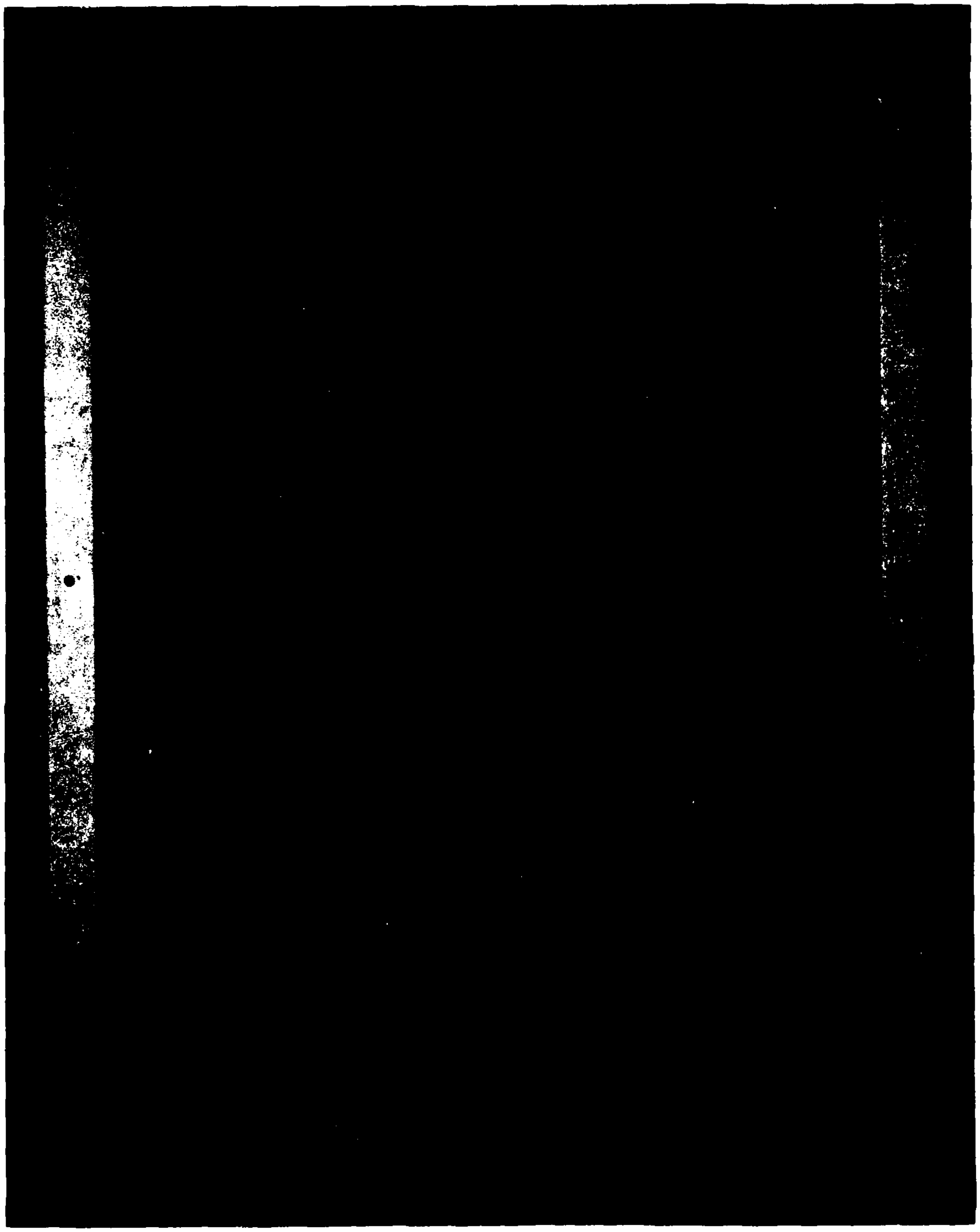


Figure 7. View Showing Internal Construction of Instrument Container.

Figure 8. Left Side of Mechanical Assembly with Tracker-Head Hardware Removed.

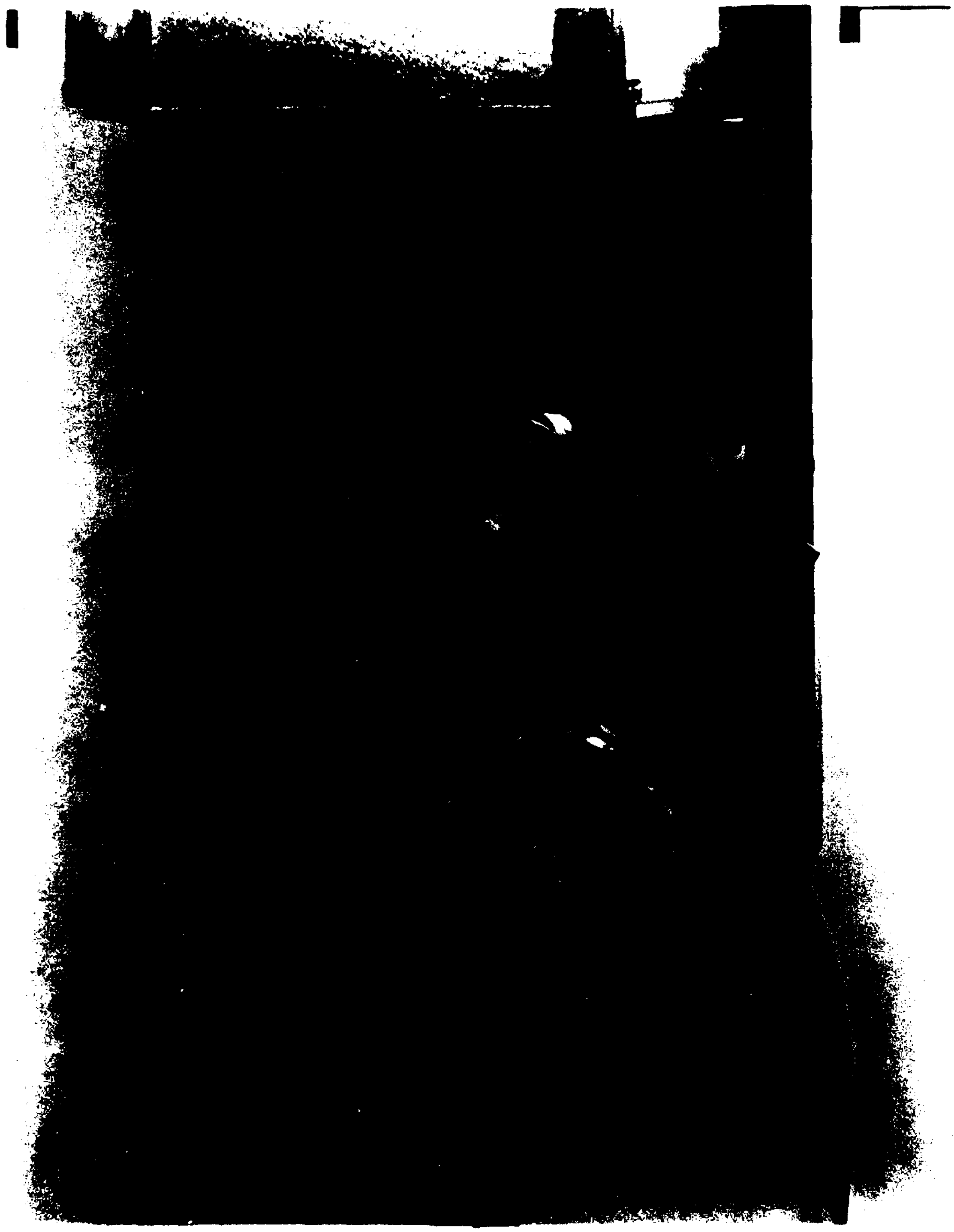


Figure 9. Right Side of Mechanical Assembly Showing Mounting Plate for Experiment.

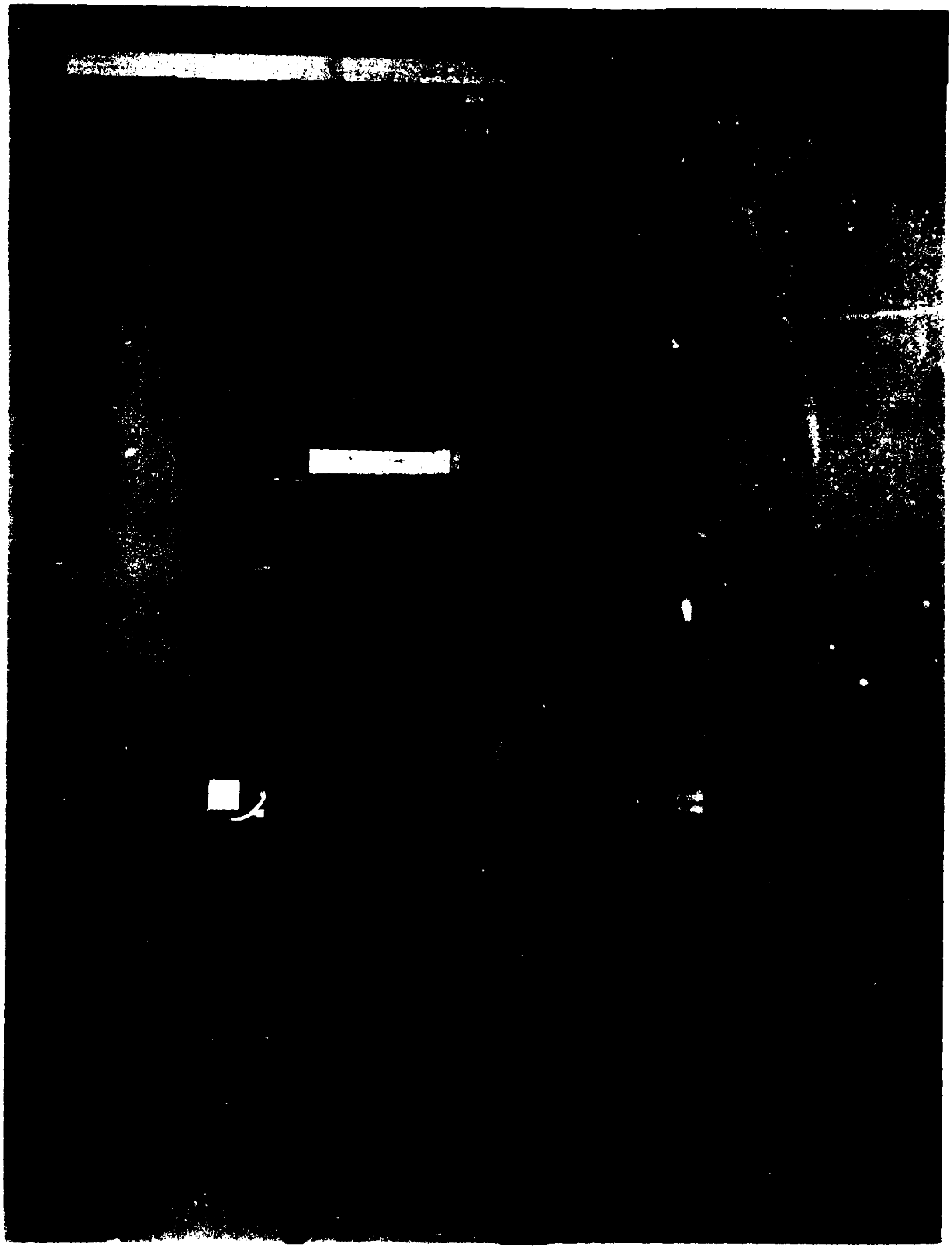


Figure 10. Rear View of Mechanical Assembly.

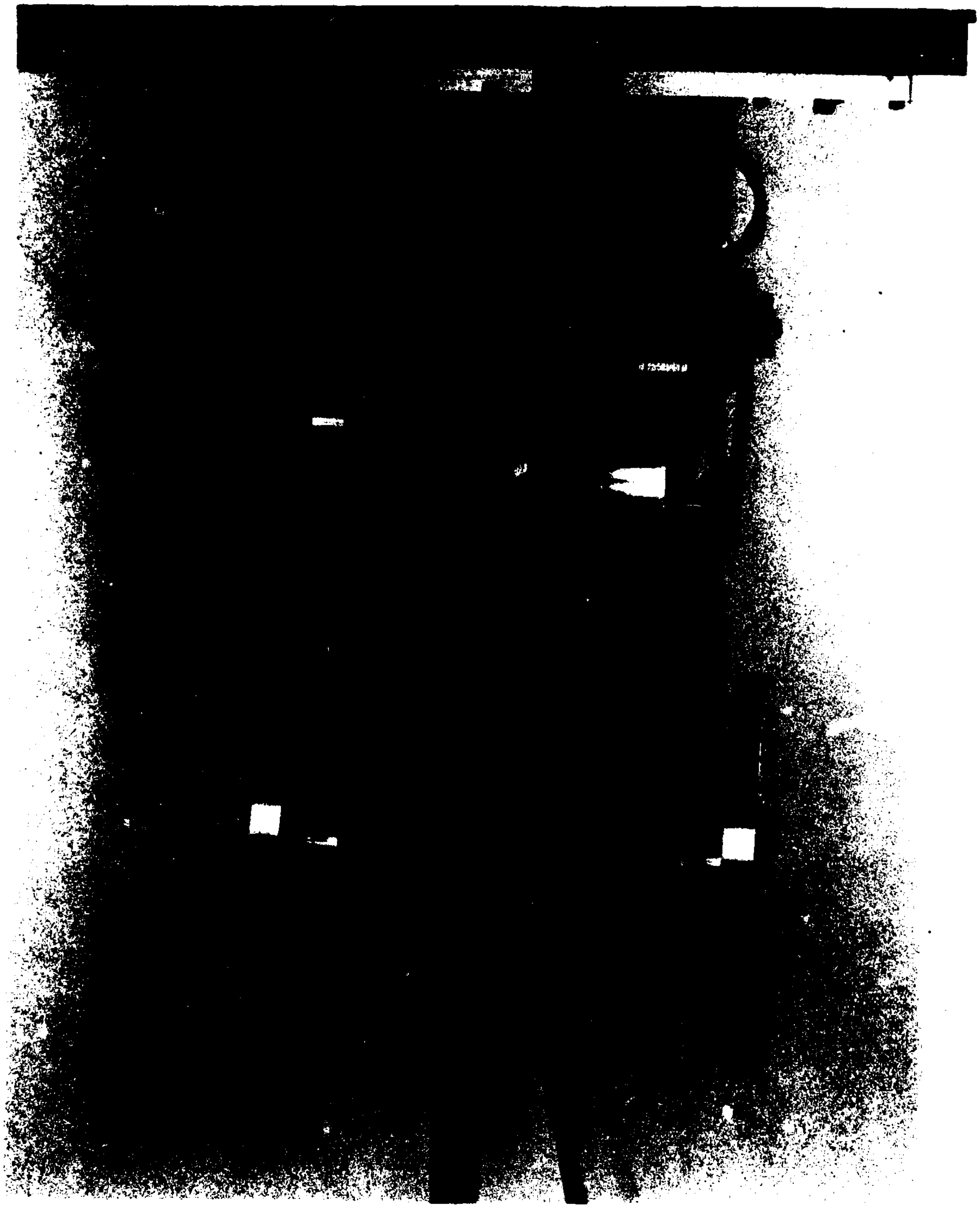


Figure 11. Front View of Mechanical Assembly.

Figure 12. Left Side of Mechanical Assembly with Instrument Package Raised to Show Regulator.

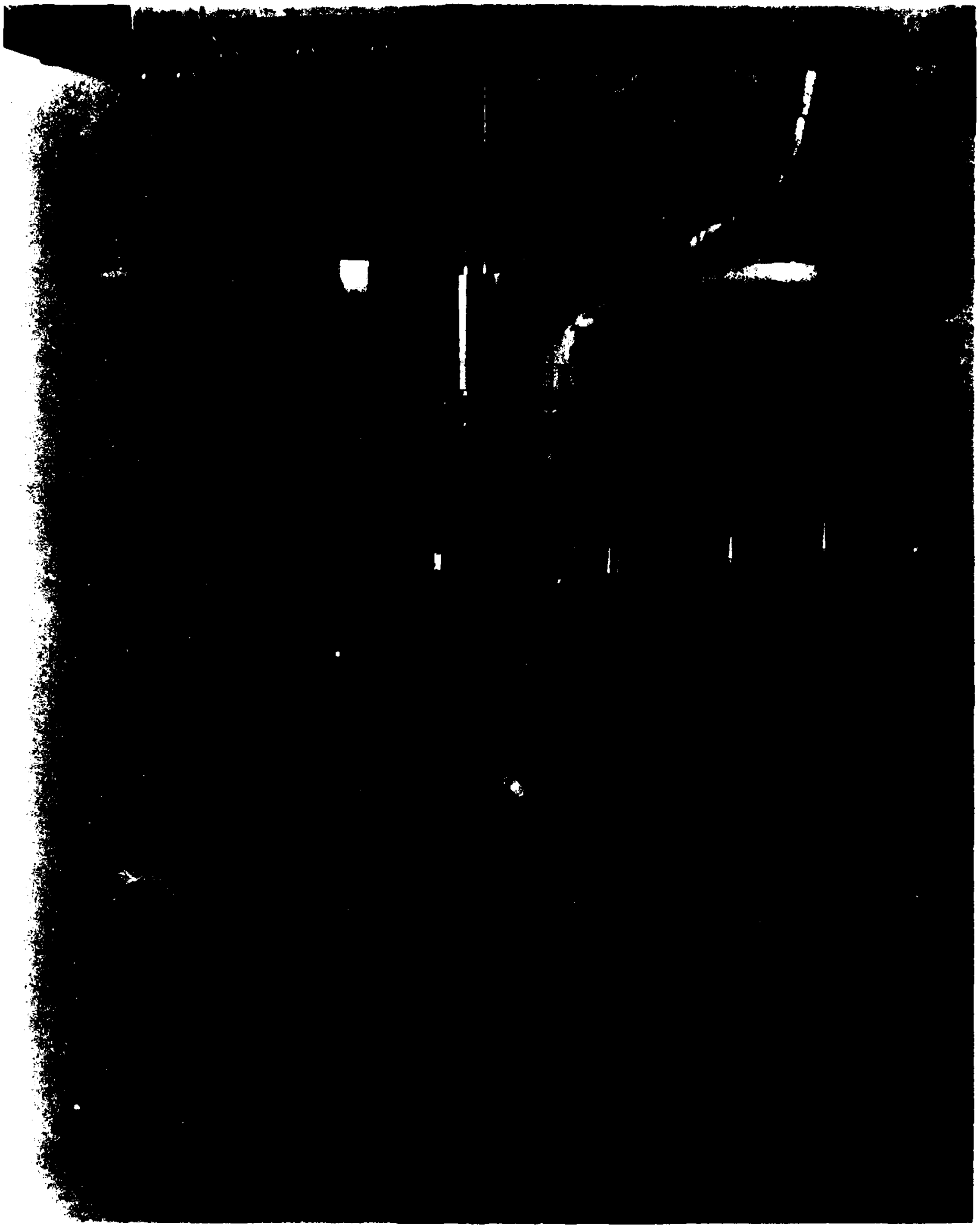


Figure 13. Left Side of Mechanical Assembly with Instrument Package Raised and Protective Barrier Removed.

Figure 14. View of Mechanical Assembly with Regulator and Protective Barrier Removed to Show Coupling, Torque Motor, and Gear Drive.

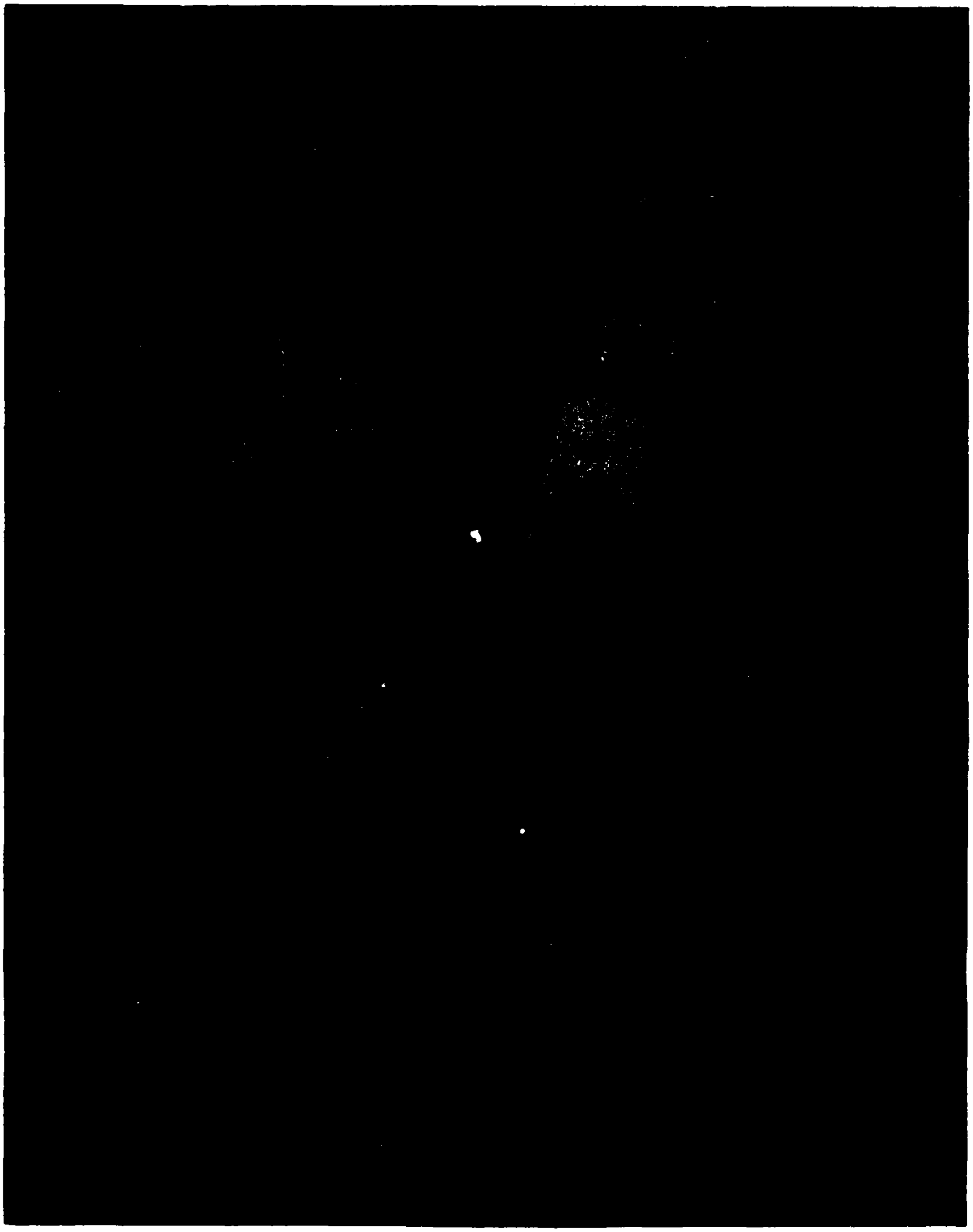


Figure 15. Hardware for Coupling Payload to Balloon, Showing Twin Anchor Lines, Bail-Attachment Fixtures, and Universal Coupling to Azimuth Shaft.

Figure 16. Coupling Hardware Showing Bails that Attach to Flying Lines.

Figure 17. Dual 27-volt Regulator and Cirkitblock DC-DC Converter.

Figure 18. Power Amplifiers, Rear View of Relay Unit, and Filter Unit.

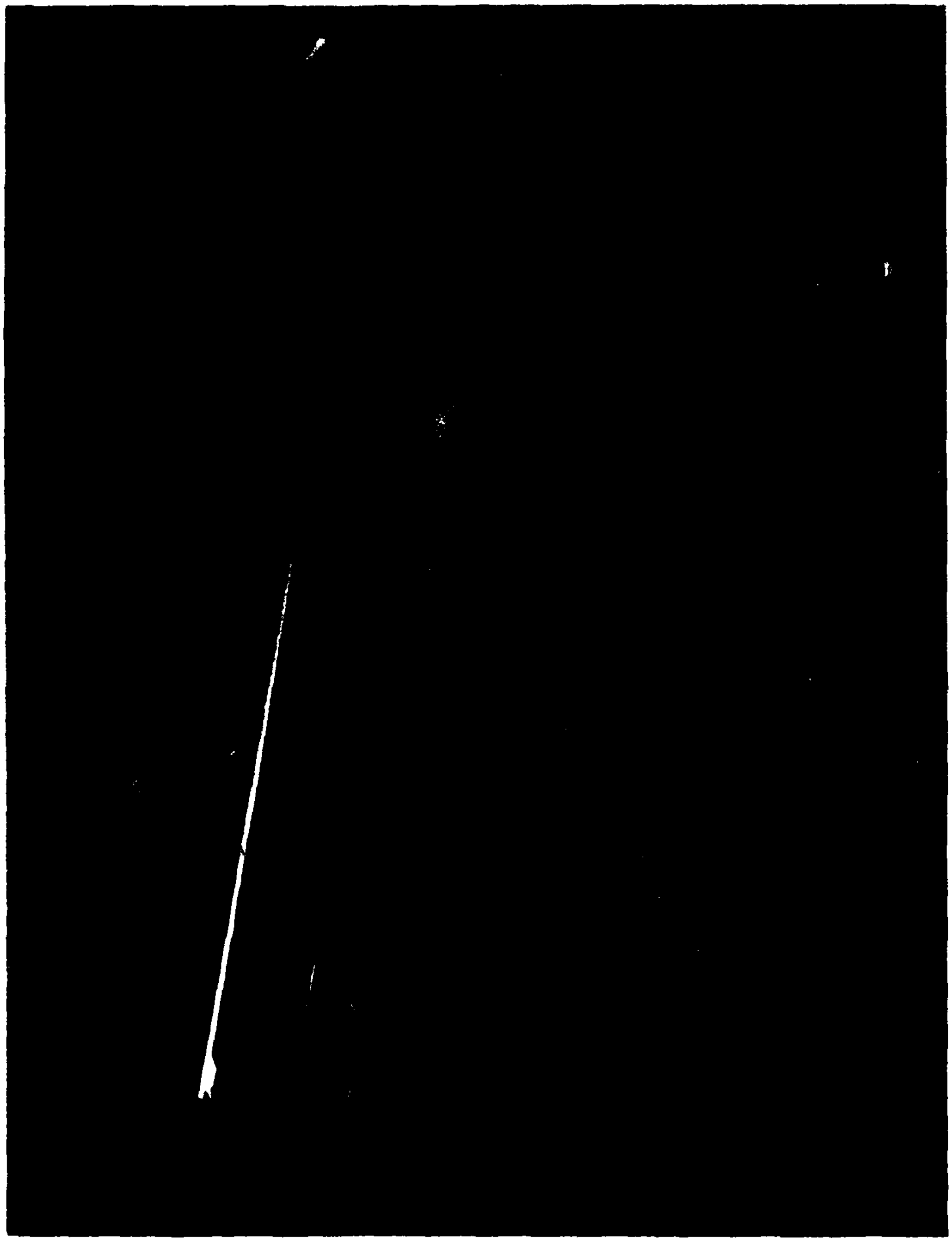


Figure 19. Electronics Unit in its Protective Cover.

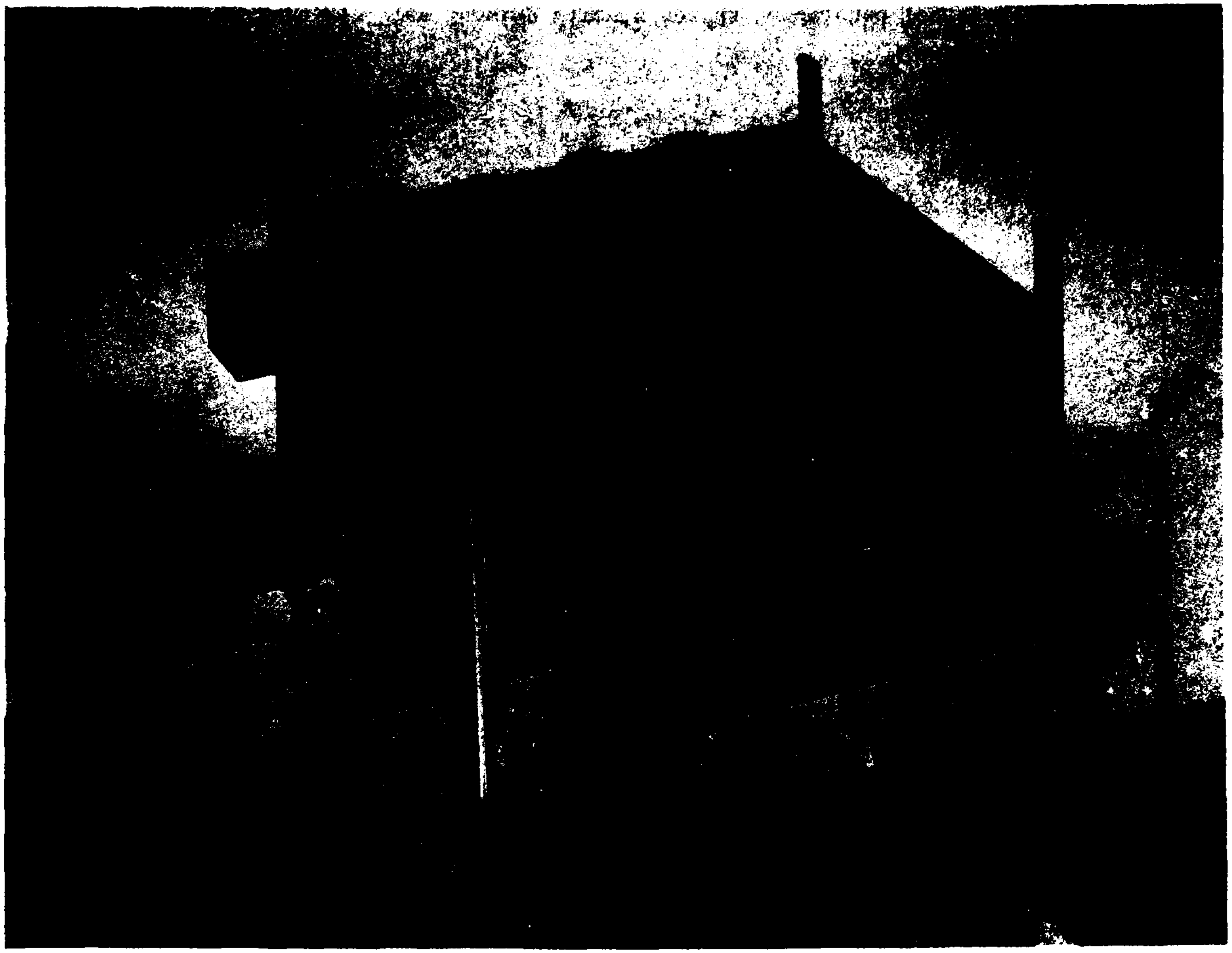


Figure 20. Electronics Unit with Protective Cover Removed.

Figure 21 View Showing Circuit Boards Sandwiched Together.

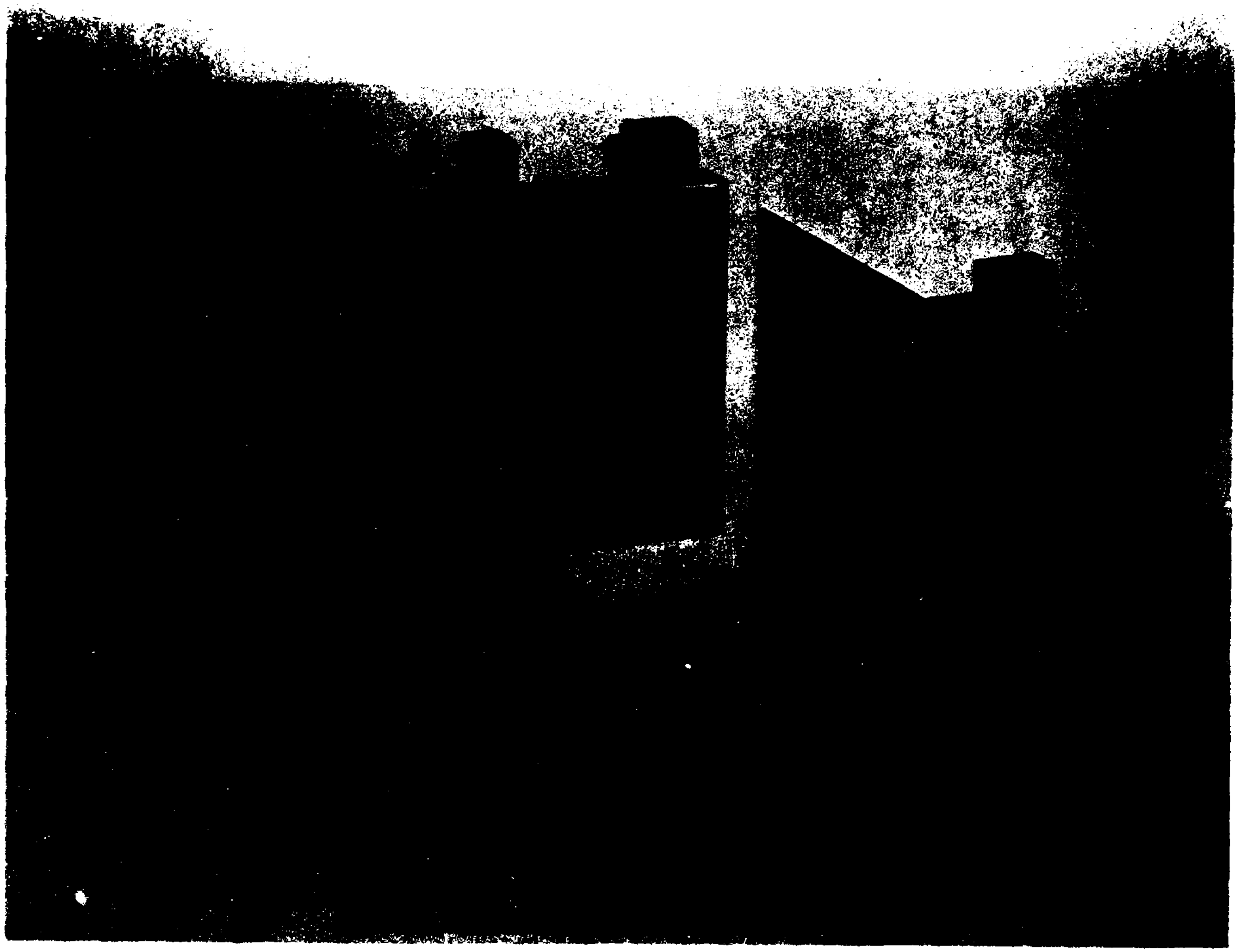


Figure 22. Sandwiched Boards Hinged Open for Testing.

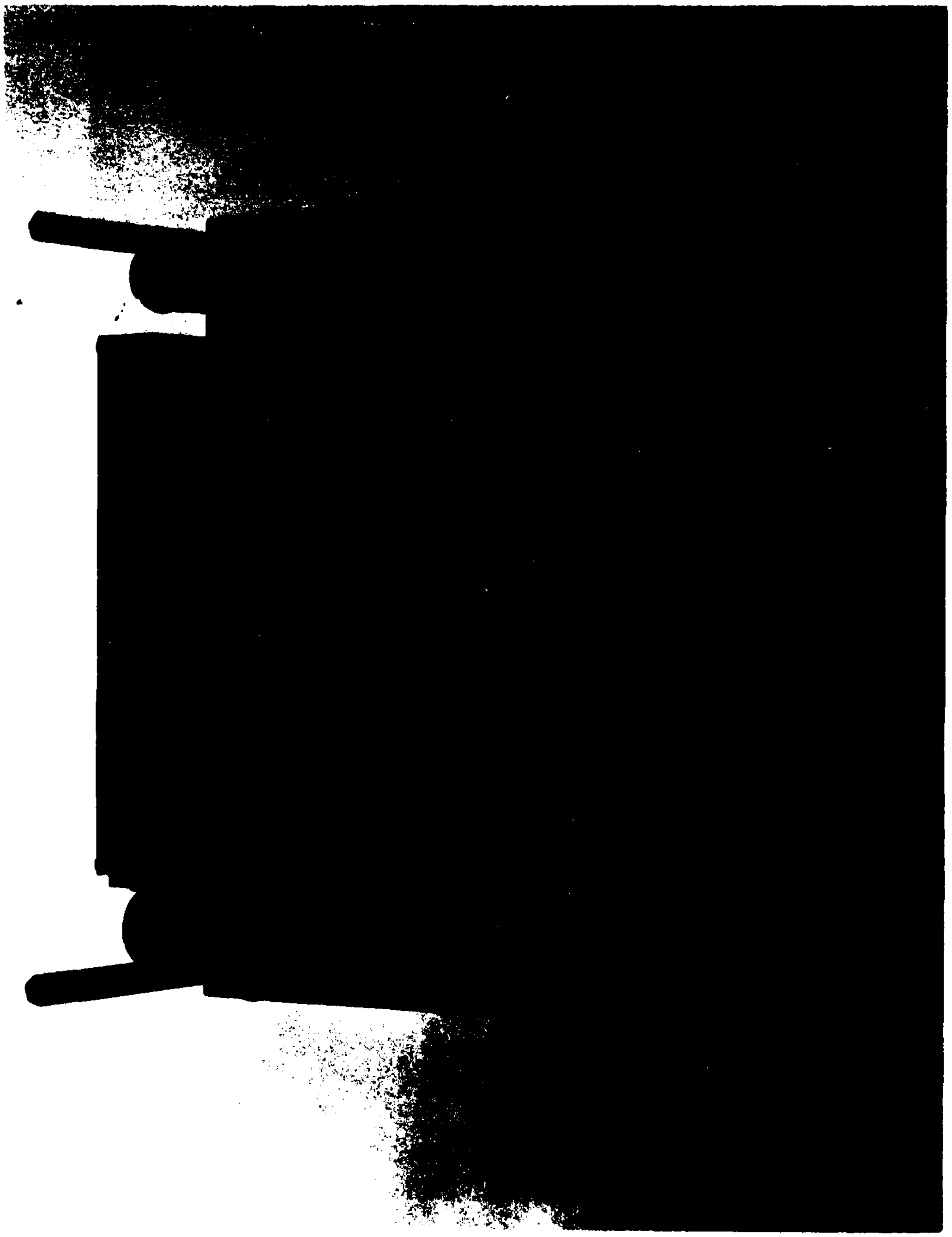


Figure 23. Upper View of Mechanical Unit.

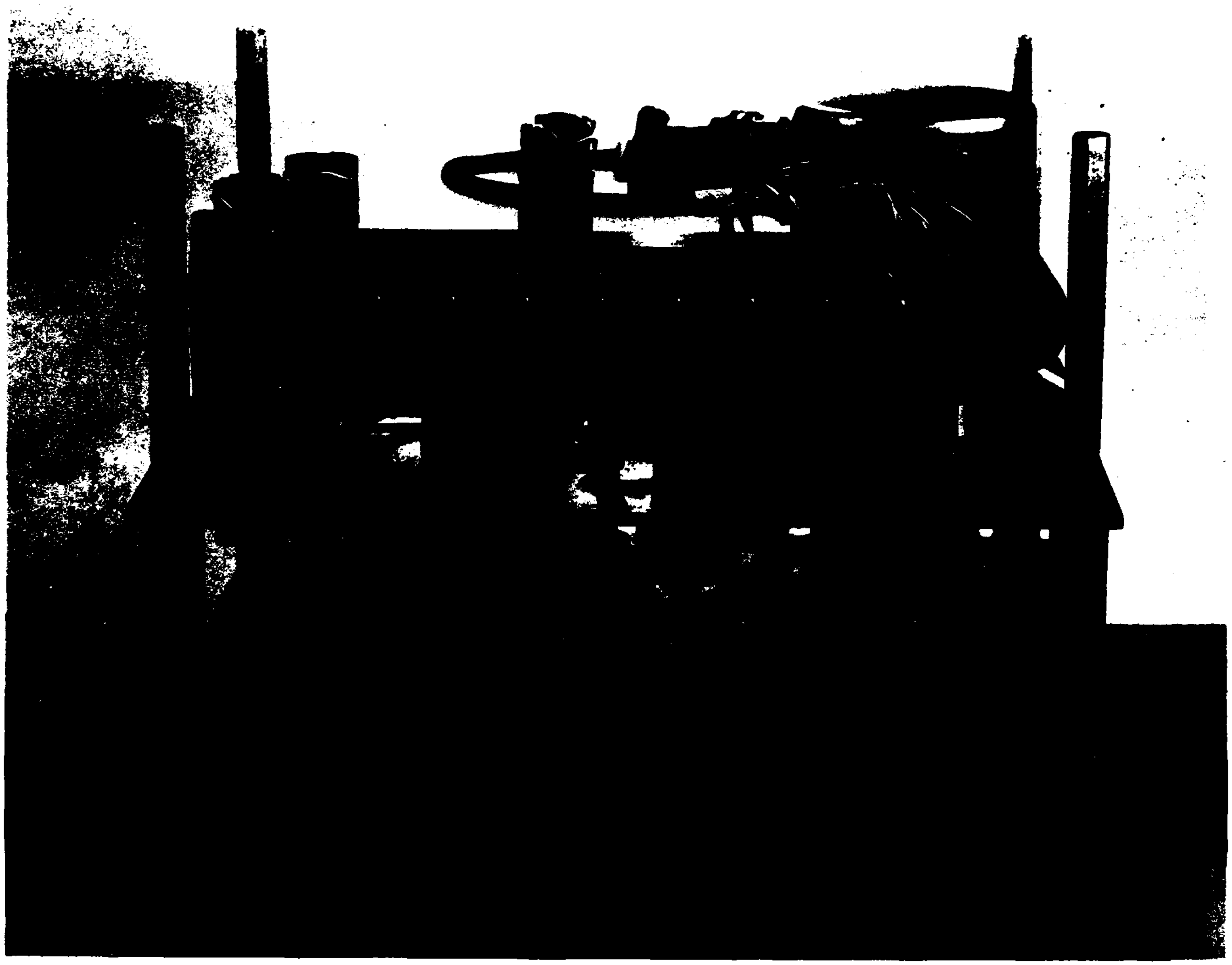


Figure 24. View of Partially Open Mechanical Unit Showing Gearing.

Figure 25. Tracker Head in Place on Mounting Disk.

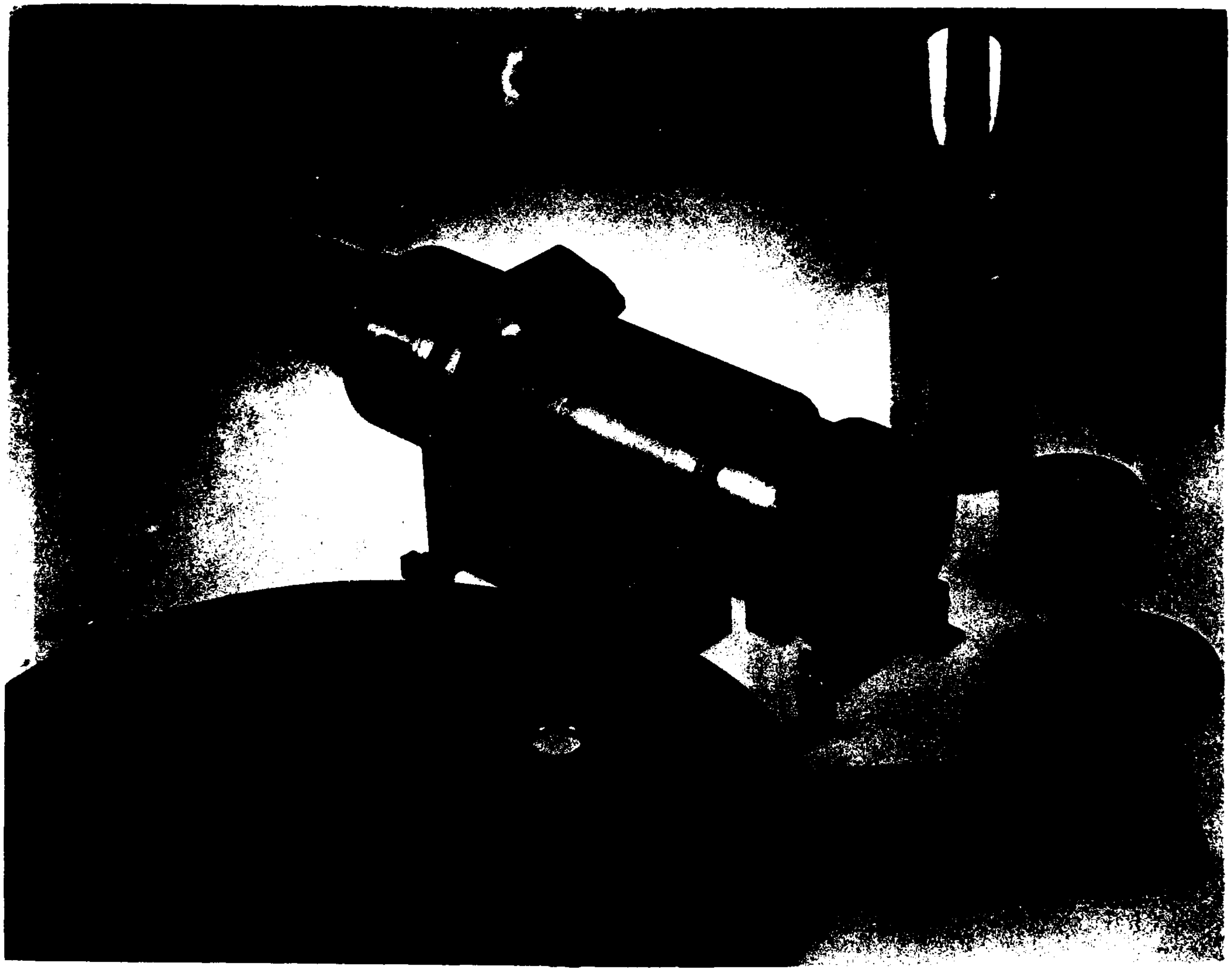


Figure 26. Photomultiplier and Optics Separated from Mounting Plate, with Lens Protection Removed, and Electronics Exposed at the Rear and Side.

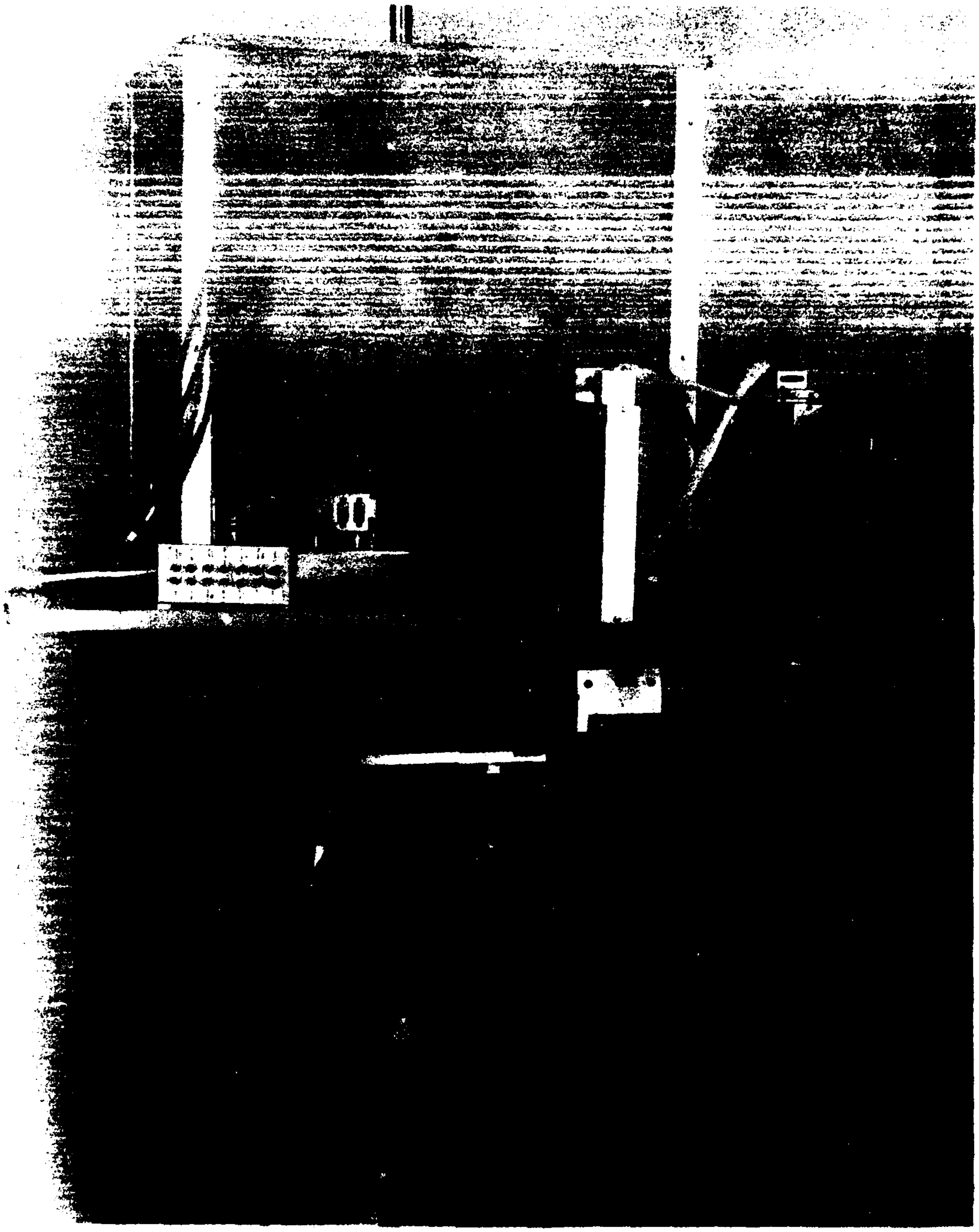
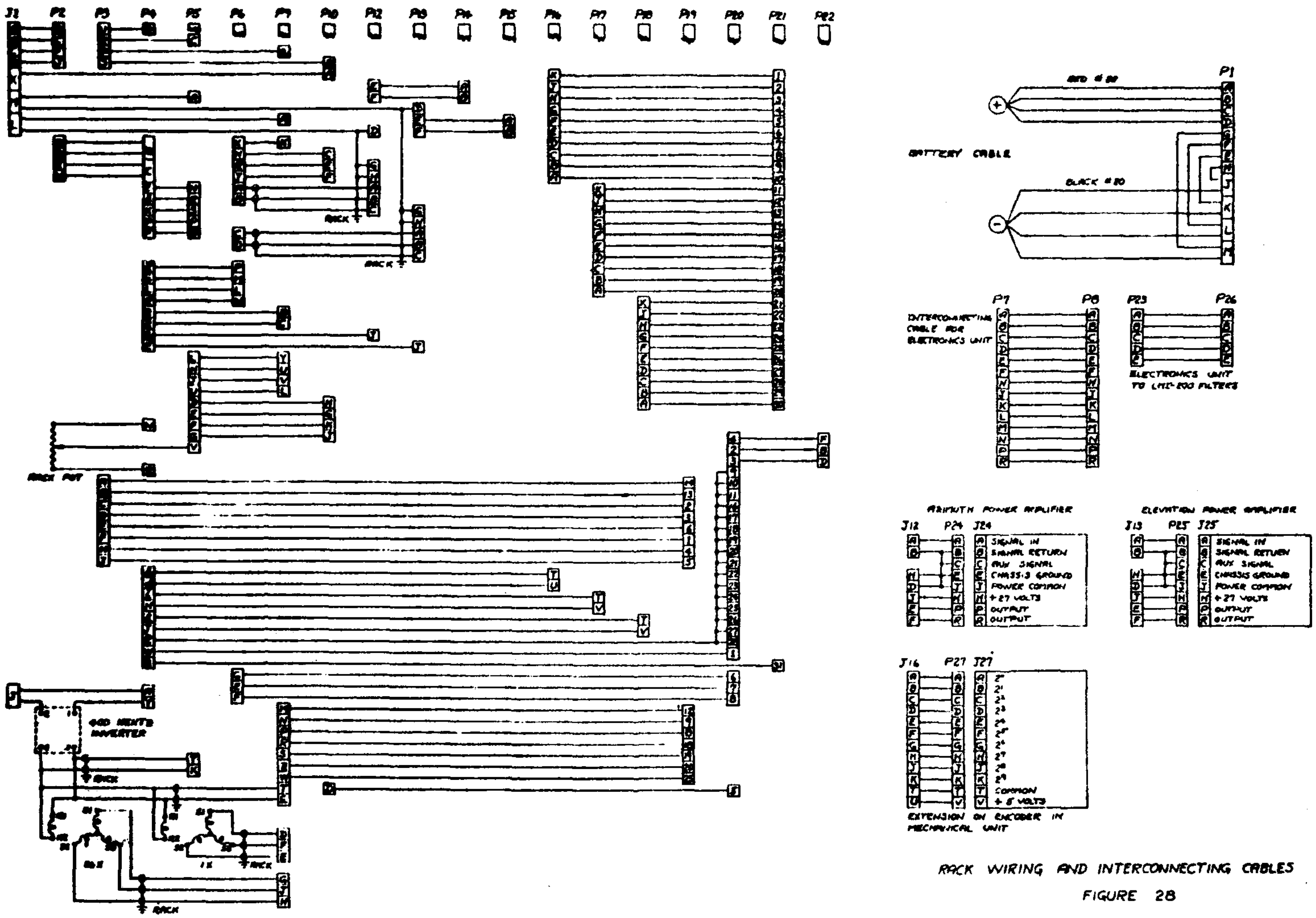
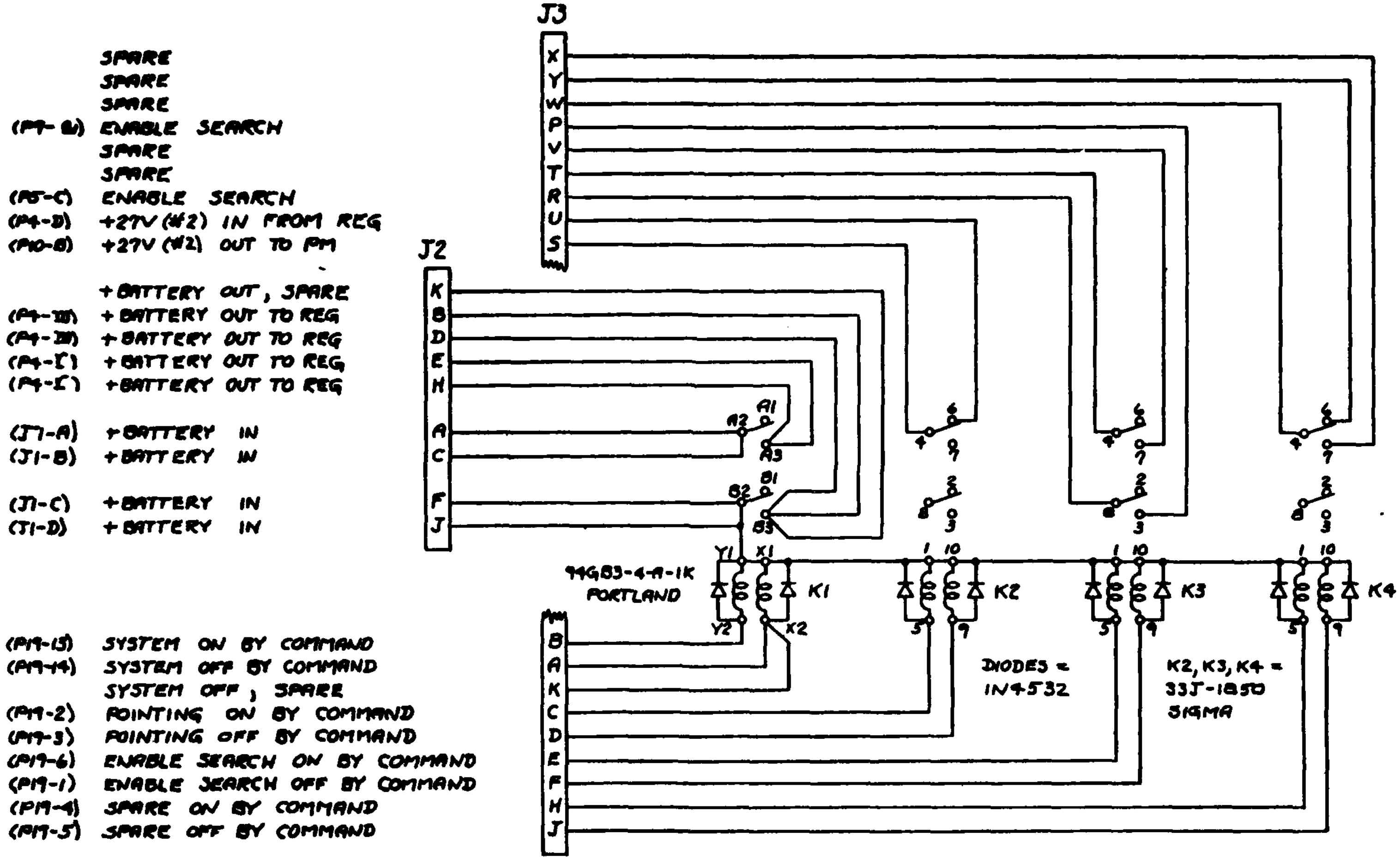


Figure 27. Test Arrangement with Opened Circuit Boards Clamped to Shelf.



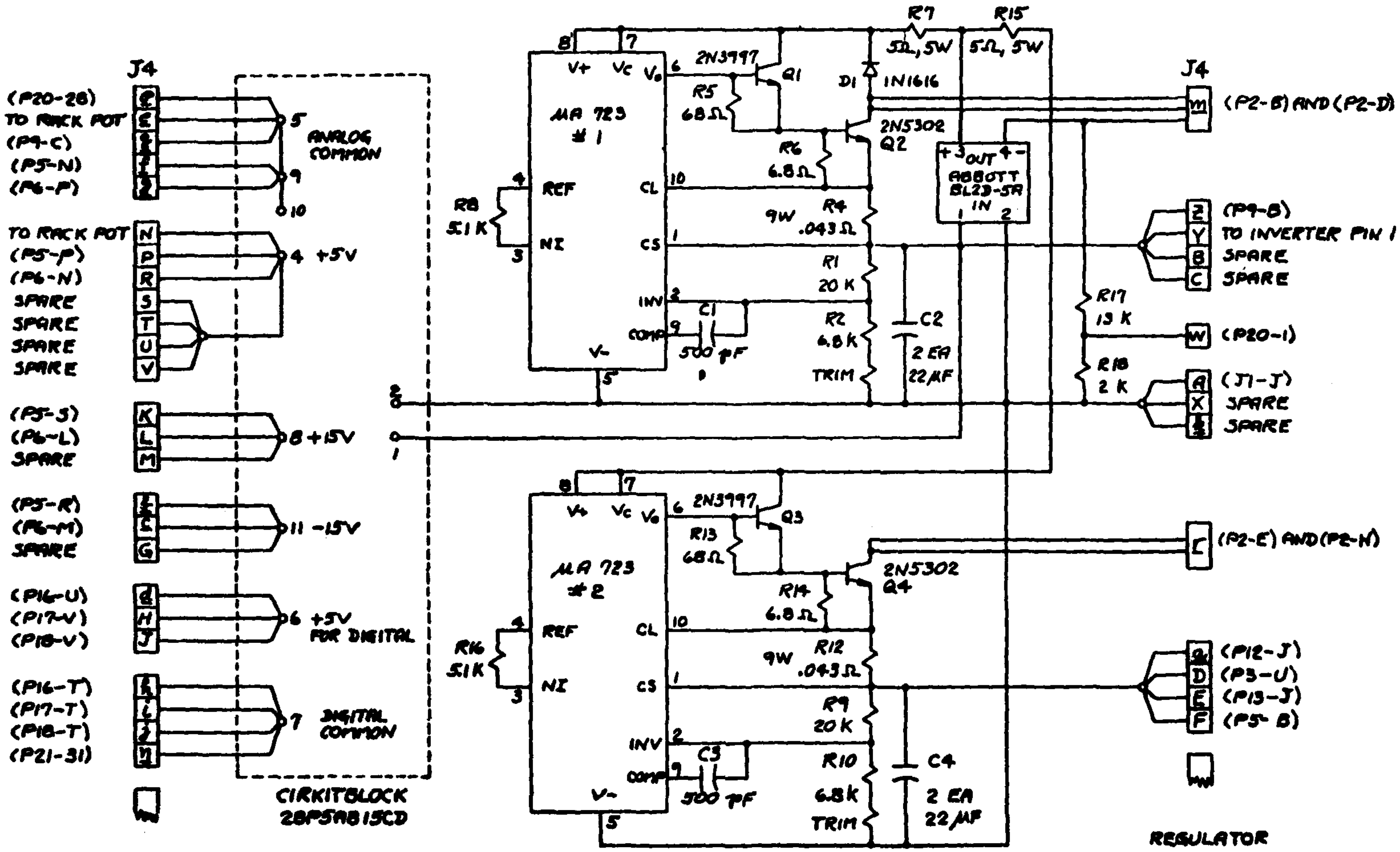
RACK WIRING AND INTERCONNECTING CABLES

FIGURE 28



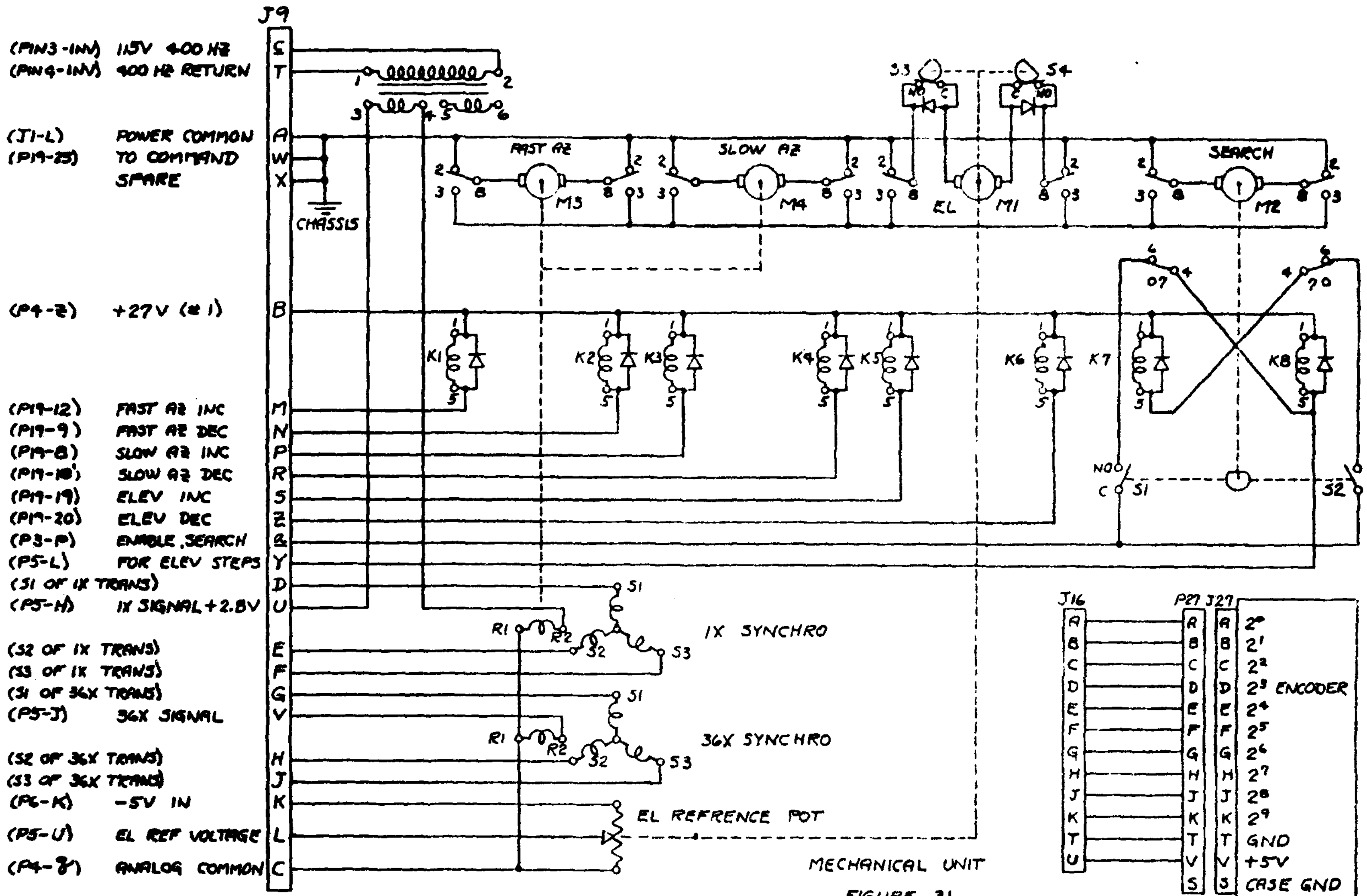
RELAY UNIT

FIGURE 29



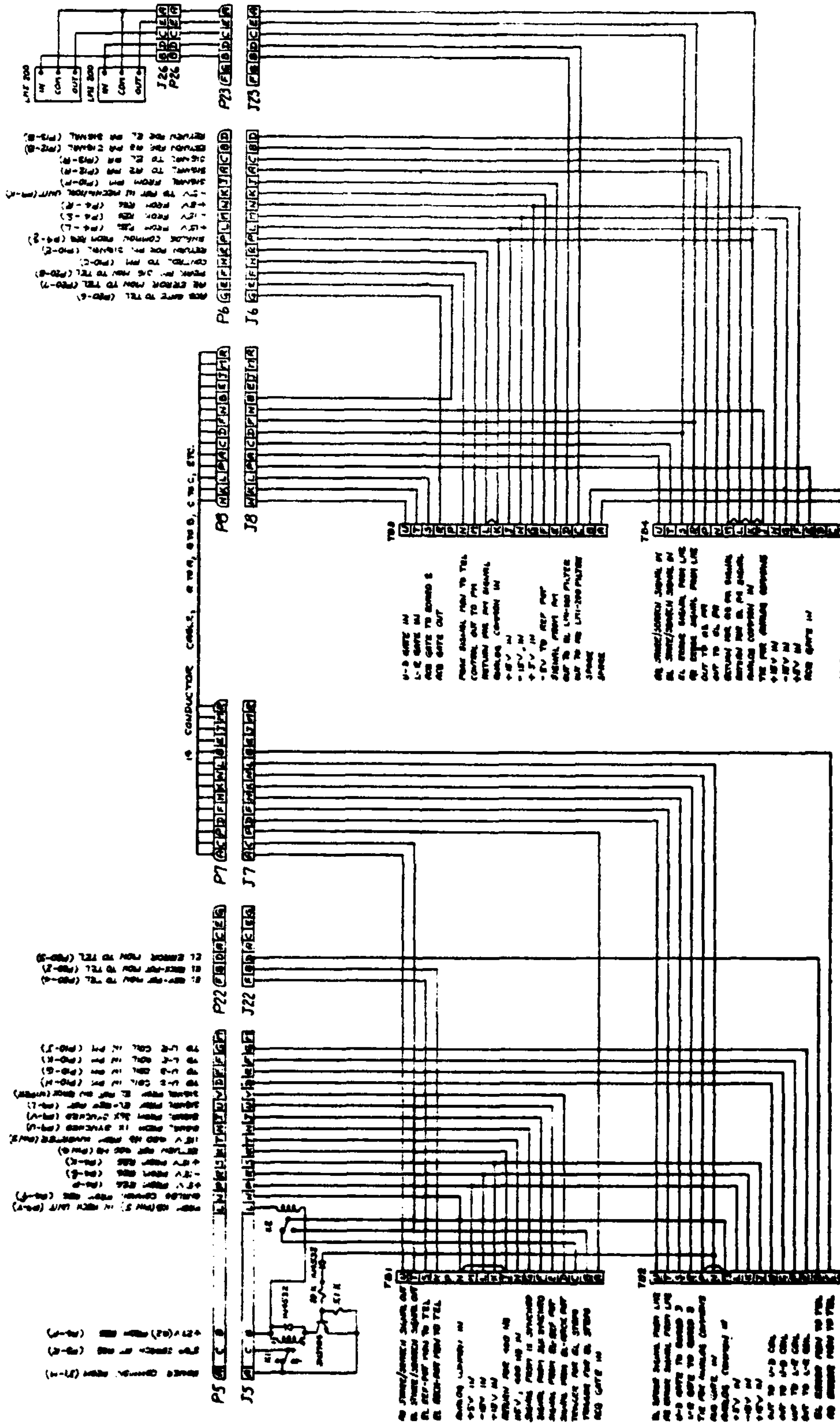
REGULATOR

FIGURE 30



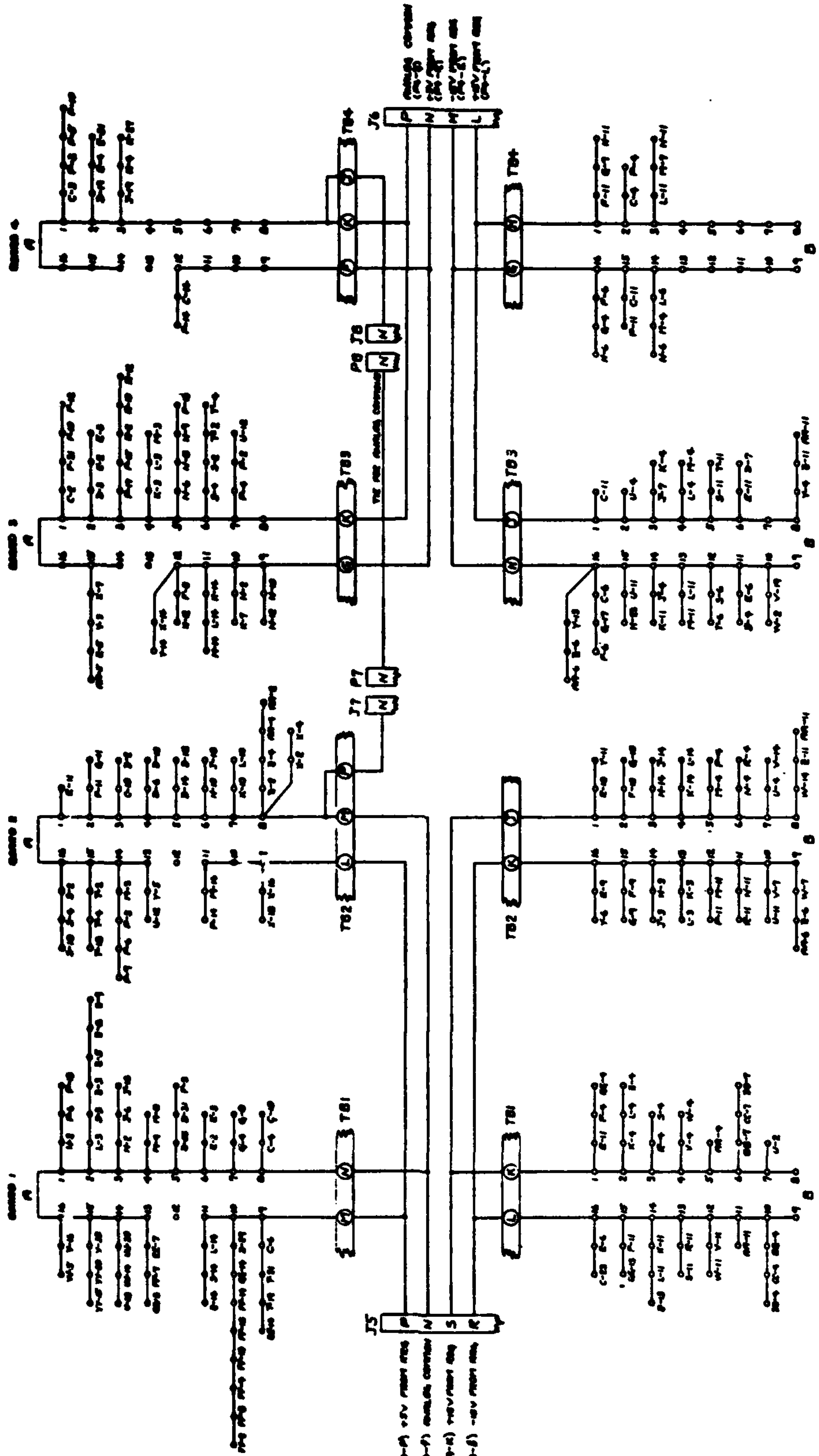
MECHANICAL UNIT

FIGURE 31



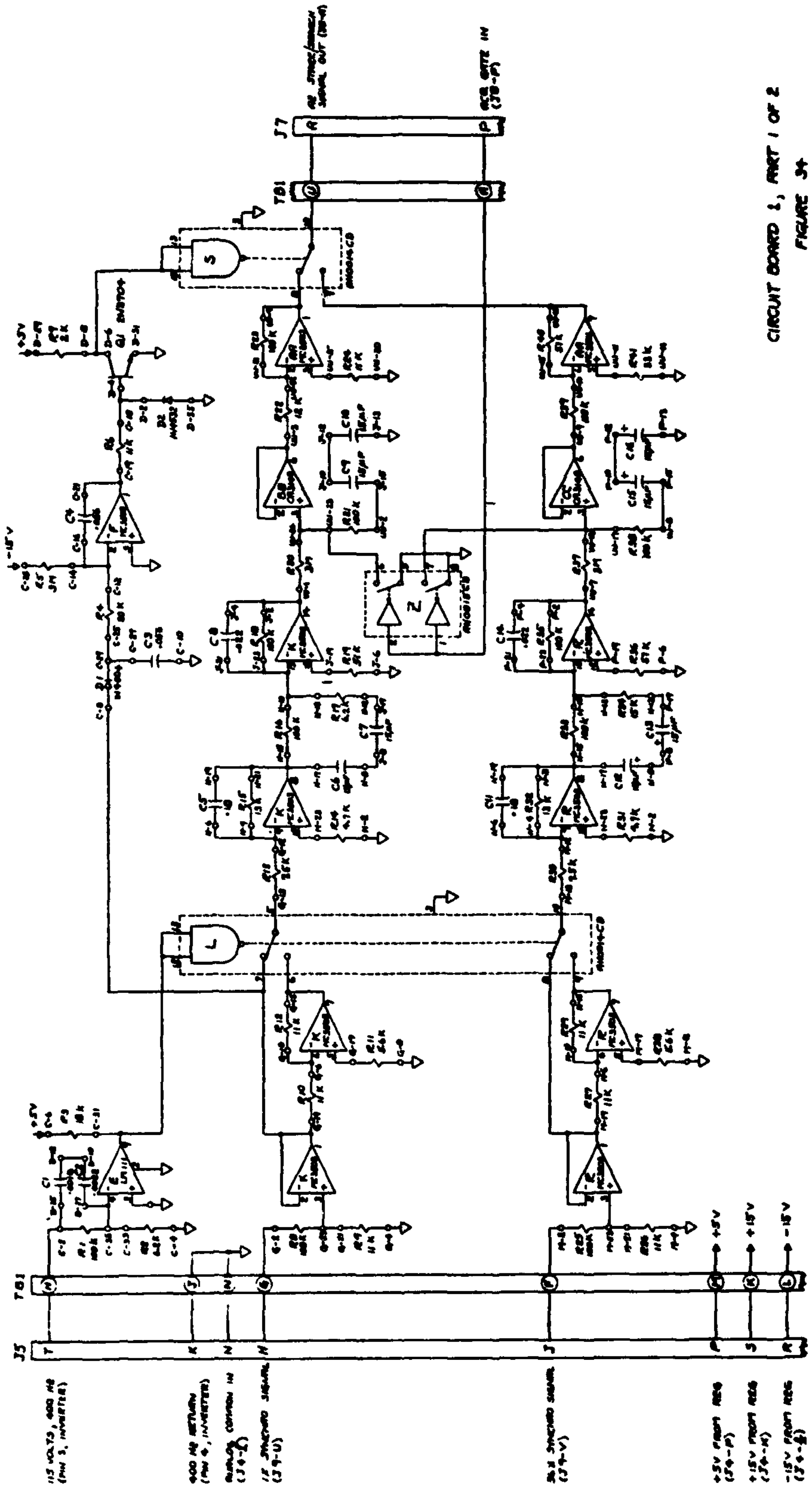
CONNECTIONS TO TERMINAL STRIPS

FIGURE 32

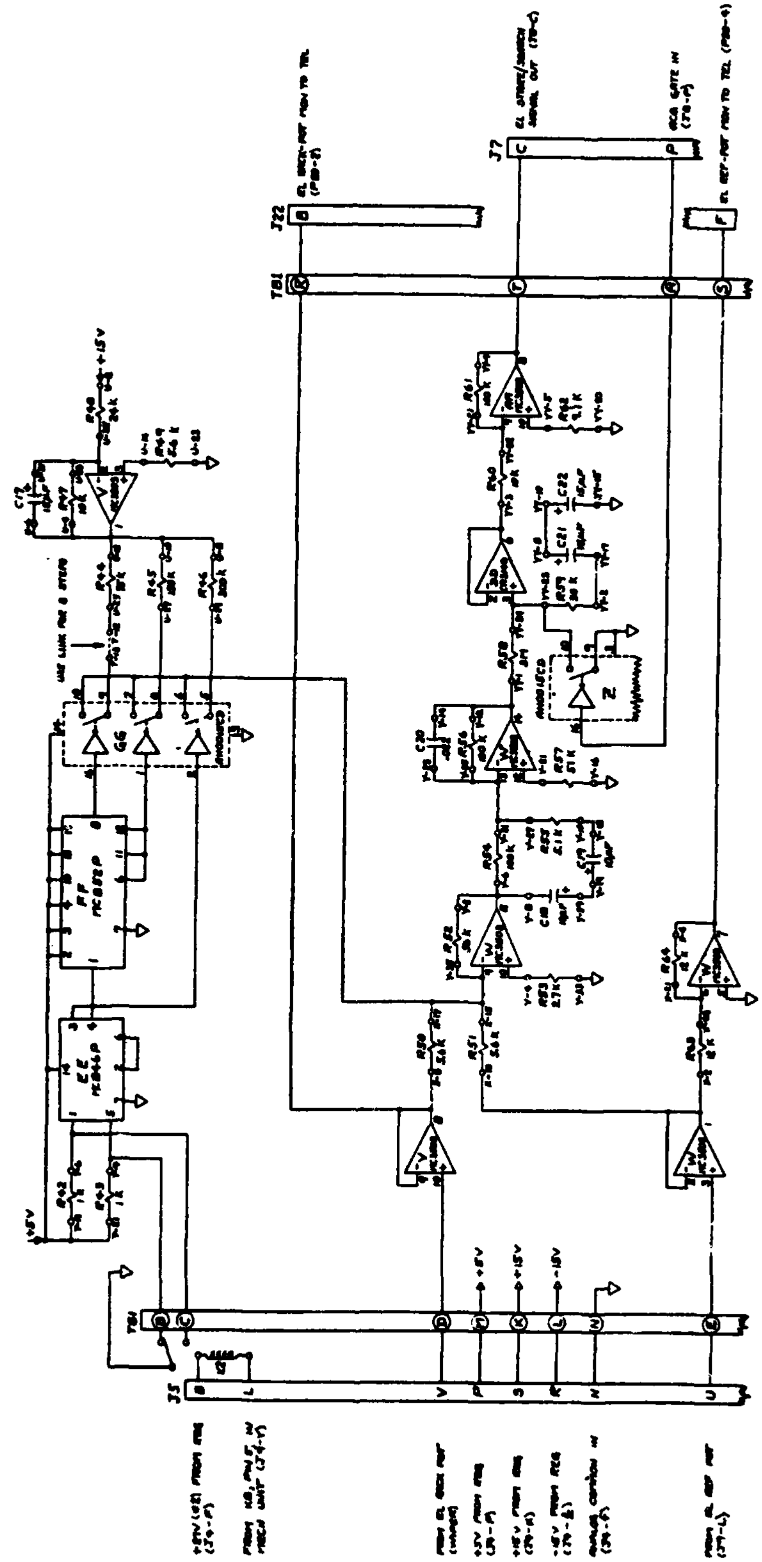


DISTRIBUTION OF VOLTAGES AND COMMONS

FIGURE 33

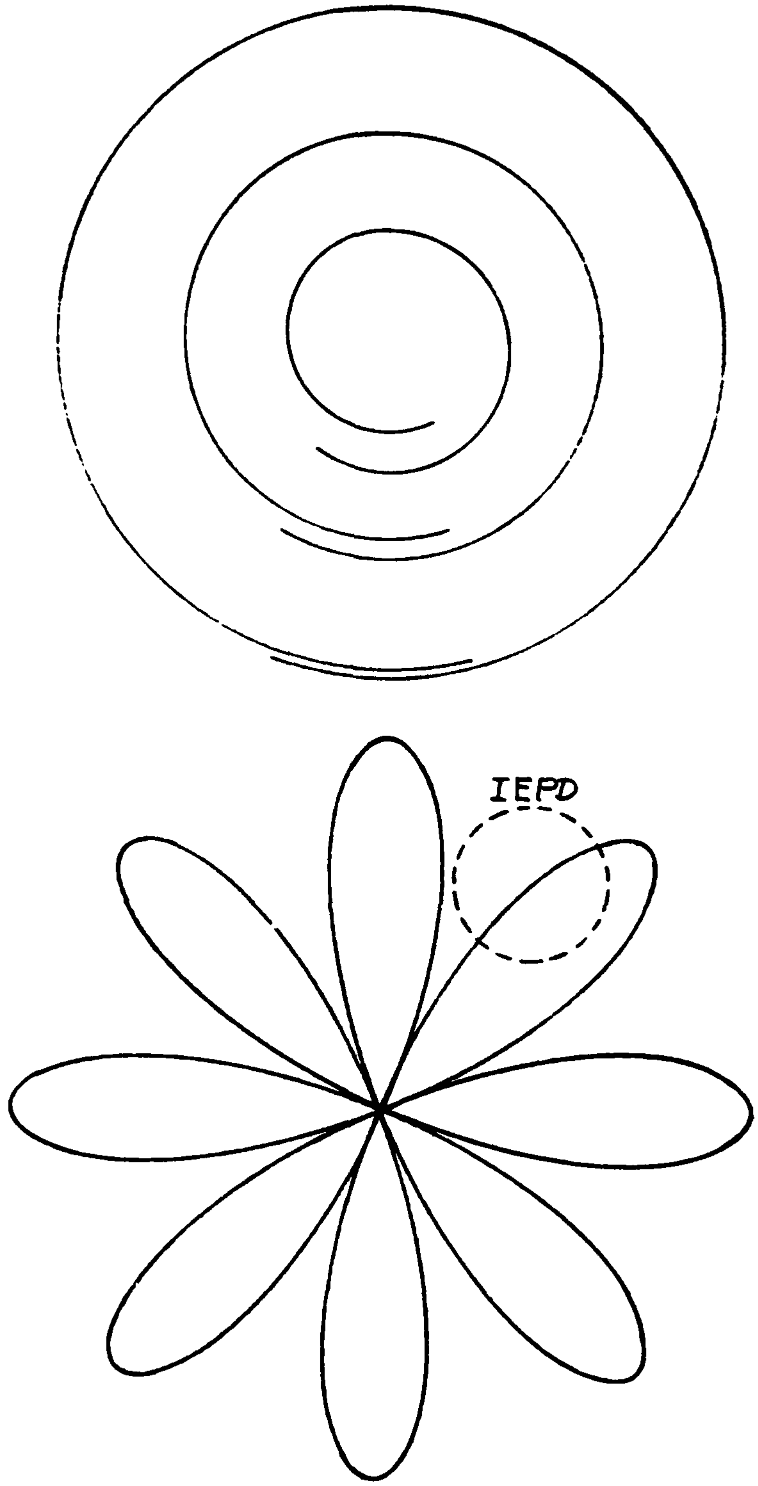


CIRCUIT BOARD 1, PART 1 OF 2
FIGURE 34



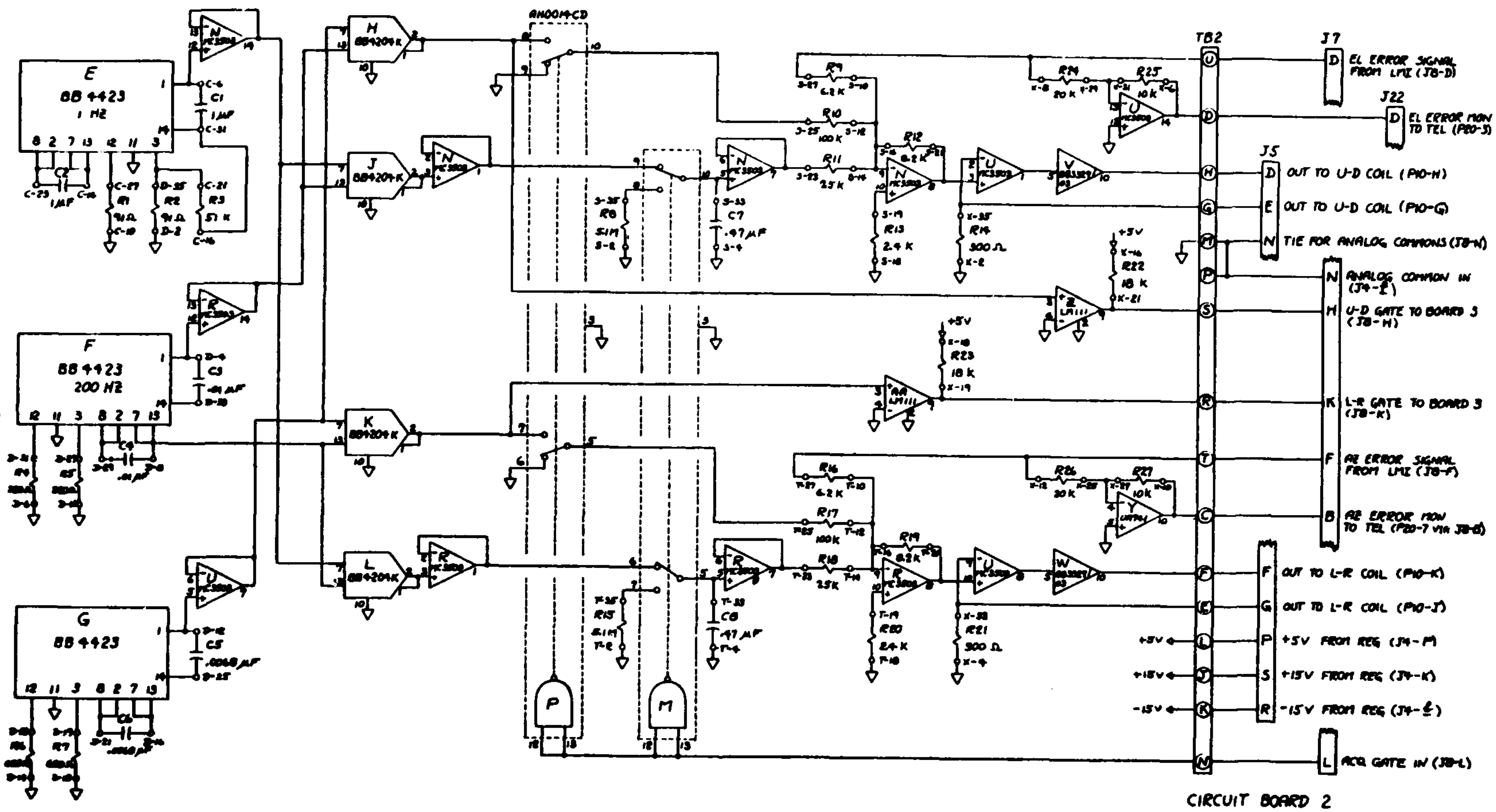
CIRCUIT BOARD 1, PART 2 OF 2

FIGURE 35



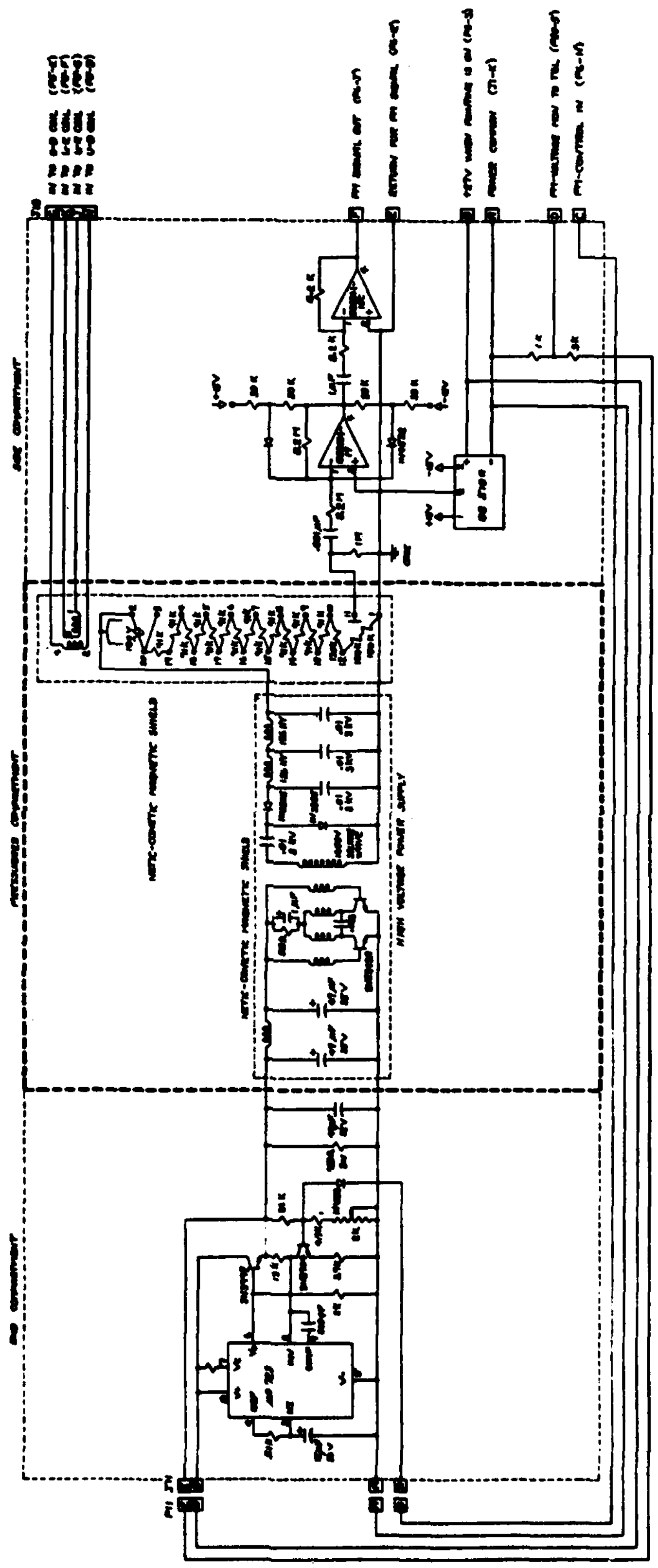
SPIRAL AND ROSETTE SCANS

FIGURE 36

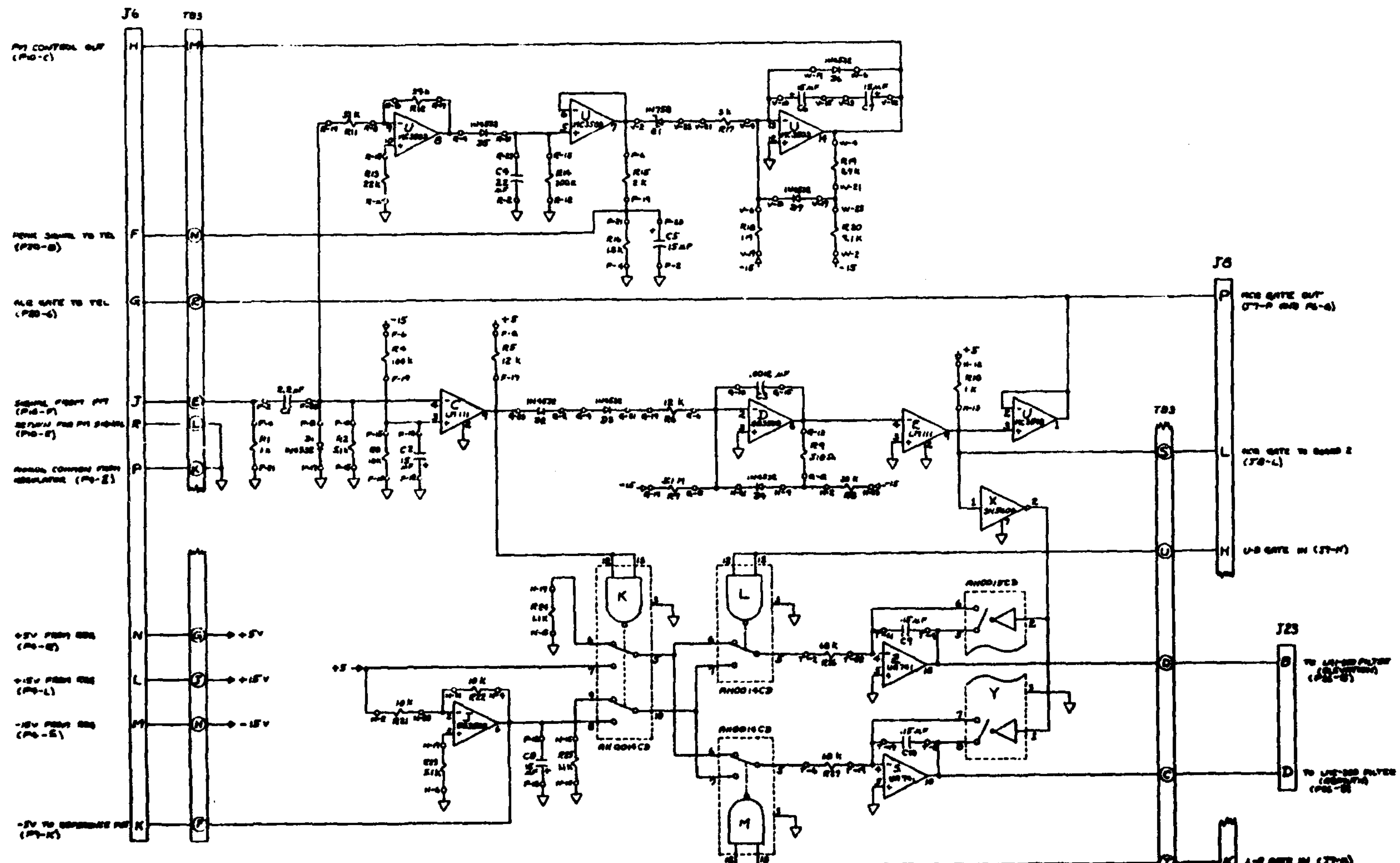


CIRCUIT BOARD 2

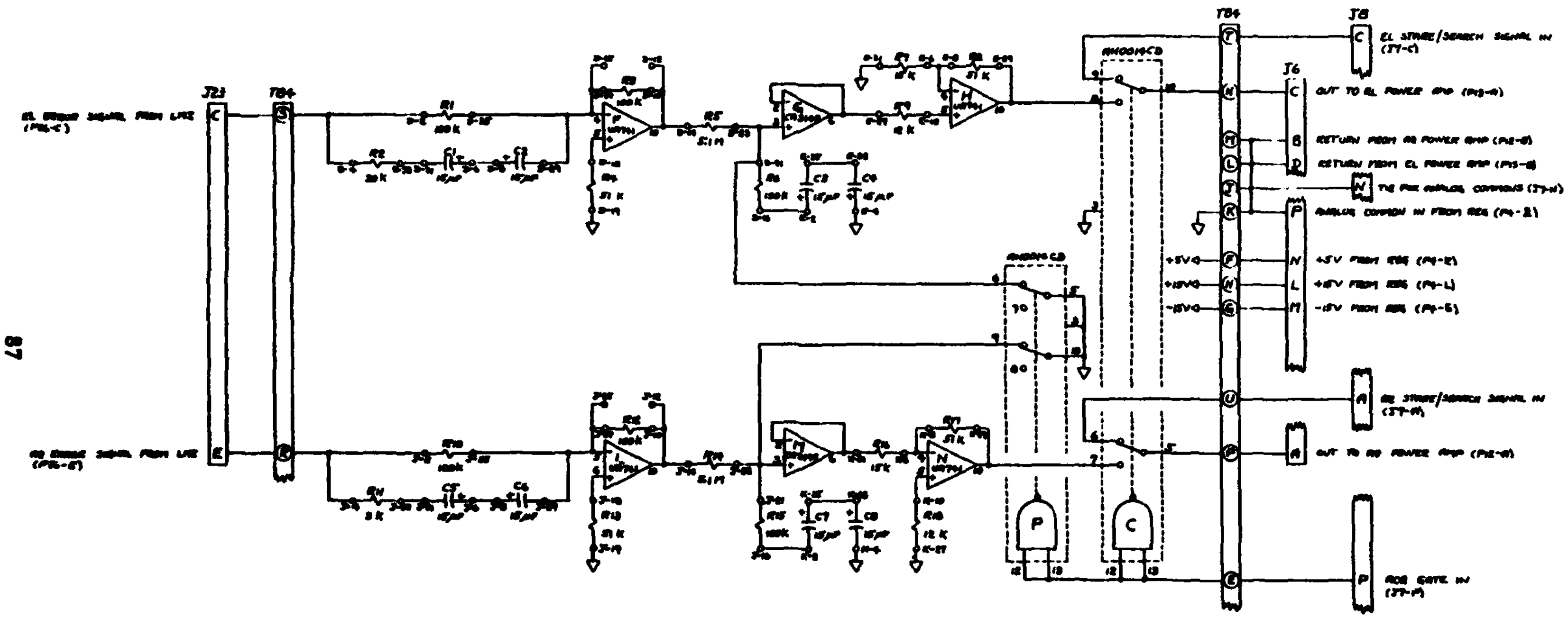
FIGURE 37



TRACKER HEAD CIRCUITRY
FIGURE 30



CIRCUIT BOARD 3
FIGURE 39



CIRCUIT BOARD 4
FIGURE 40

APPENDIX A

Plug Designations

Number	Location	Type
J1	Battery Power Junction	PT02A-14-12P
P2	Relay Unit, Power In/Out	MRA-9S
P3	Relay Unit, Coils and Contacts	MRE-21S
P4	Regulator	PT06A-20-39S(SR)
P5	Electronics Unit, 19-pin	PT06A-14-19S(SR)
P6	Electronics Unit, 15-pin	PT06A-14-15S(SR)
P7	Electronics Unit, Boards 1 & 2	SMI-14F
P8	Electronics Unit, Boards 3 & 4	SMI-14F
P9	Mechanical Unit	PT06A-16-26S(SR)
P10	Photomultiplier Unit (On Side)	PT06A-12-10S(SR)
P11	Photomultiplier Unit (On Back)	PT06A-10-6S(SR)
P12	On AZ Power Amplifier	PT02A-12-10S(SR)
P13	On EL Power Amplifier	PT02A-12-10S(SR)
P14	AZ Torque Motor	PT06A-8-3S(SR)
P15	EL Torque Motor	PT06A-8-3S(SR)
P16	Mechanical Unit	PT06A-14-18S(SR)

Number		Type
P17	AZ Shaft Encoder on Rack	PT06A-14-19S(SR)
P18	EL Shaft Encoder on Rack	PT06A-14-19S(SR)
P19	Command Unit	DEM25P
P20	Telemetering Unit (Analog)	DCM37S
P21	Telemetering Unit (Digital)	DDM50S
P22	Electronics Unit to Telemetering	SMI7F
P23	Electronics Unit to LMI Filters	SMI7F
P24	On Bottom of AZ Power Amplifier	MRA-14S
P25	On Bottom of EL Power Amplifier	MRA-14S
P26	On LMI Assembly	PT02A-10-6S(SR)
P27	AZ Shaft Encoder in Mechanical Unit	PT06A-14-19S(SR)

APPENDIX B

Parts List for Electronic Circuit Boards

Sockets on the four boards in the electronics unit carry either circuit modules or headers. Listed here for each board are the components carried by the headers, including pin designations, and the modules used in each socket.

PARTS LIST FOR ELECTRONICS UNIT, BOARD 1

UNIT A BUSS

A-1 thru A-8 and A-13 thru A-16	Analog Common
A-9 thru A-11	+5 volts

UNIT B BUSS

B-1 thru B-8	+15 volts
B-9 thru B-16	-15 volts

UNIT C COMPONENT CARRIER

C-2 to C-35	R1	100 k, 1/4 watt
C-4 to C-33	R2	6.2 k, 1/4 watt
C-6 to C-31	R3	18 k, 1/4 watt
C-8 to C-29	D1	1N4004
C-10 to C-27	C3	0.056 μF, 50 volt
C-12 to C-25	R4	20 k, 1/4 watt
C-14 to C-23	R5	3 meg, 1/4 watt
C-16 to C-21	C4	0.056 μF, 50 volt
C-18 to C-19	R6	11 k, 1/4 watt

UNIT D COMPONENT CARRIER

D-2 to D-35		D2	1N4532
D-4	Base	Q1	2N3704
D-6	Collector	Q1	
D-31	Emitter	Q1	
D-8 to D-29		R7	2 k, 1/4 watt
D-10 to D-27		C2	0.0022 μF, 100 volt
D-12 to D-25		C1	0.0018 μF, 100 volt

UNIT E COMPONENT

Comparator, National Semiconductor LM111

UNIT F COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT G COMPONENT CARRIER

G-2 to G-23	R8	100 k, 1/4 watt
G-4 to G-21	R9	11 k, 1/4 watt
G-6 to G-19	R10	11 k, 1/4 watt

PARTS LIST FOR ELECTRONICS UNIT, BOARD 1 (cont.)

UNIT G COMPONENT CARRIER

G-8 to G-17	R11	5.6 k, 1/4 watt
G-10 to G-15	R12	11 k, 1/4 watt
G-12 to G-13	R13	7.5 k, 1/4 watt

UNIT H COMPONENT CARRIER

H-2 to H-23	R14	4.7 k, 1/4 watt
H-4 to H-21	R15	13 k, 1/4 watt
H-6 to H-19	C5	0.18 μF, 50 volt
H-8 to H-17	C6	15 μF, 20 volt Tantalex
H-10 to H-15	R16	100 k, 1/4 watt
H-12 to H-13	R17	6.2 k, 1/4 watt

UNIT J COMPONENT CARRIER

J-2 to J-23	R18	100 k, 1/4 watt
J-4 to J-21	C8	0.022 μF, 100 volt
J-6 to J-19	R19	51 k, 1/4 watt
J-8 to J-17	C7	15 μF, 20 volt Tantalex
J-10 to J-15	C9	15 μF, 20 volt Tantalex
J-12 to J-13	C10	15 μF, 20 volt Tantalex

UNIT K COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT L COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

UNIT M COMPONENT CARRIER

M-2 to M-23	R25	100 k, 1/4 watt
M-4 to M-21	R26	11 k, 1/4 watt
M-6 to M-19	R27	11 k, 1/4 watt
M-8 to M-17	R28	5.6 k, 1/4 watt
M-10 to M-15	R29	11 k, 1/4 watt
M-12 to M-13	R30	7.5 k, 1/4 watt

UNIT N COMPONENT CARRIER

N-2 to N-23	R31	4.7 k, 1/4 watt
N-4 to N-21	R32	13 k, 1/4 watt

PARTS LIST FOR ELECTRONICS UNIT, BOARD 1 (cont.)

UNIT N COMPONENT CARRIER

N-6 to N-19	C11	0.18 μF, 50 volt
N-8 to N-17	C12	15 μF, 20 volt Tantalex
N-10 to N-15	R33	100 k, 1/4 watt
N-12 to N-13	R34	15 k, 1/4 watt

UNIT P COMPONENT CARRIER

P-2 to P-23	R35	100 k, 1/4 watt
P-4 to P-21	C14	0.022 μF, 100 volt
P-6 to P-19	R36	51 k, 1/4 watt
P-8 to P-17	C13	15 μF, 20 volt Tantalex
P-10 to P-15	C15	15 μF, 20 volt Tantalex
P-12 to P-13	C16	15 μF, 20 volt Tantalex

UNIT R COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT S COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

UNIT T COMPONENT CARRIER

T-4 to T-21	R43	1 k, 1/4 watt
T-6 to T-19	R42	1 k, 1/4 watt
T-12 to T-13	Link	Use for eight steps

UNIT U COMPONENT CARRIER

U-2 to U-35	R48	24 k, 1/4 watt
U-4 to U-33	R47	10 k, 1/4 watt
U-6 to U-31	C17	15 μF, 20 volt Tantalex
U-8 to U-29	R46	300 k, 1/4 watt
U-10 to U-27	R45	150 k, 1/4 watt
U-12 to U-25	R44	75 k, 1/4 watt
U-14 to U-23	R49	5.6 k, 1/4 watt

UNIT V COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT W COMPONENT

Quad Operational Amplifier, Motorola MC3503L

PARTS LIST FOR ELECTRONICS UNIT, BOARD 1 (cont.)

UNIT X COMPONENT CARRIER

X-2 to X-23	R63	12 k, 1/4 watt
X-4 to X-21	R64	12 k, 1/4 watt
X-8 to X-17	R50	5.6 k, 1/4 watt
X-10 to X-15	R51	5.6 k, 1/4 watt

UNIT Y COMPONENT CARRIER

Y-2 to Y-35	R52	56 k, 1/4 watt
Y-4 to Y-33	R53	2.7 k, 1/4 watt
Y-6 to Y-31	R54	100 k, 1/4 watt
Y-8 to Y-29	C18	10 μF, 20 volt Tantalex
Y-10 to Y-27	R55	5.1 k, 1/4 watt
Y-12 to Y-25	R56	100 k, 1/4 watt
Y-14 to Y-23	C20	0.022 μF, 100 volt
Y-16 to Y-21	R57	51 k, 1/4 watt
Y-18 to Y-19	C19	10 μF, 20 volt Tantalex

UNIT Z COMPONENT

Quad Analog Switch, National Semiconductor AH0015CB

UNIT AA COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT BB COMPONENT

FET Operational Amplifier, RCA CA3140S

UNIT CC COMPONENT

FET Operational Amplifier, RCA CA3140S

UNIT DD COMPONENT

FET Operational Amplifier, RCA CA3140S

UNIT EE COMPONENT

Quad Two-Input NAND Gates, Motorola MC846P

UNIT FF COMPONENT

Dual J-K Flip-Flop, Motorola 852P

UNIT GG COMPONENT

Quad Analog Switch, National Semiconductor AH0015CD

PARTS LIST FOR ELECTRONICS UNIT, BOARD 1 (cont.)

UNIT UU COMPONENT CARRIER

UU-1 to UU-24	R20	3 meg, 1/4 watt
UU-2 to UU-23	R21	100 k, 1/4 watt
UU-3 to UU-22	R22	12 k, 1/4 watt
UU-4 to UU-21	R23	100 k, 1/4 watt
UU-5 to UU-20	R24	11 k, 1/4 watt
UU-7 to UU-18	R37	3 meg, 1/4 watt
UU-8 to UU-17	R38	100 k, 1/4 watt
UU-9 to UU-16	R39	100 k, 1/4 watt
UU-10 to UU-15	R40	51 k, 1/4 watt
UU-11 to UU-14	R41	33 k, 1/4 watt

UNIT YY COMPONENT CARRIER

YY-1 to YY-24	R58	3 meg, 1/4 watt
YY-2 to YY-23	R59	30 k, 1/4 watt
YY-3 to YY-22	R60	10 k, 1/4 watt
YY-4 to YY-21	R61	100 k, 1/4 watt
YY-5 to YY-20	R62	9.1 k, 1/4 watt
YY-8 to YY-17	C21	15 μF, 20 volt Tantalex
YY-10 to YY-15	C22	15 μF, 20 volt Tantalex

AD-A118 770 TUFTS UNIV MEDFORD MA DEPT OF ELECTRICAL ENGINEERING F/G 1/3
POINTING PAYLOAD FOR SINGLE TETHER BALLOONS.(U)
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PARTS LIST FOR ELECTRONICS UNIT, BOARD 2

UNIT A BUSS

A-1 thru A-8 and A-13 thru A-16	Analog Common
A-9 thru A-11	+5 volts

UNIT B BUSS

B-1 thru B-8	+15 volts
B-9 thru B-16	-15 volts

UNIT C COMPONENT CARRIER

C-6 to C-31	C1	1.0 F, 200 volt
C-10 to C-27	R1	91 ohm, 1/4 watt
C-14 to C-23	C2	1.0 μF, 200 volt
C-16 to C-21	R3	51 k, 1/4 watt

UNIT D COMPONENT CARRIER

D-2 to D-35	R2	91 ohm, 1/4 watt
D-4 to D-33	C3	0.01 μF, 100 volt
D-6 to D-31	R4	220 ohm, 1/4 watt in parallel with 4.7 k, 1/8 watt
D-8 to D-29	C4	0.01 μF, 100 volt
D-10 to D-27	R5	200 ohm, 1/4 watt in parallel with 4.7 k 1/8 watt
D-12 to D-25	C5	0.0068 μF, 100 volt
D-14 to D-23	R6	680 ohm, 1/4 watt
D-16 to D-21	C6	0.0068 μF, 100 volt
D-18 to D-19	R7	680 ohm, 1/4 watt

UNIT E COMPONENT

Quadrature Oscillator, Burr-Brown 4423

UNIT F COMPONENT

Quadrature Oscillator, Burr-Brown 4423

UNIT G COMPONENT

Quadrature Oscillator, Burr-Brown 4423

UNIT H COMPONENT

Multiplier, Burr-Brown 4204K

PARTS LIST FOR ELECTRONICS UNIT, BOARD 2 (cont.)

UNIT J COMPONENT

Multiplier, Burr-Brown 4204K

UNIT K COMPONENT

Multiplier, Burr-Brown 4204K

UNIT L COMPONENT

Multiplier, Burr-Brown 4204K

UNIT M COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

UNIT N COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT P COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

UNIT R COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT S COMPONENT CARRIER

S-2 to S-35	R8	5.1 meg, 1/4 watt
S-4 to S-33	C7	0.47 μF, 50 volt
S-10 to S-27	R9	6.2 k, 1/4 watt
S-12 to S-25	R10	100 k, 1/4 watt
S-14 to S-23	R11	7.5 k, 1/4 watt
S-16 to S-21	R12	8.2 k, 1/4 watt
S-18 to S-19	R13	2.4 k, 1/4 watt

UNIT T COMPONENT CARRIER

T-2 to T-35	R15	5.1 meg, 1/4 watt
T-4 to T-33	C8	0.47 μF, 50 volt
T-10 to T-27	R16	6.2 k, 1/4 watt
T-12 to T-25	R17	100 k, 1/4 watt
T-14 to T-23	R18	7.5 k, 1/4 watt
T-16 to T-21	R19	8.2 k, 1/4 watt
T-18 to T-19	R20	2.4 k, 1/4 watt

PARTS LIST FOR ELECTRONICS UNIT, BOARD 2 (cont.)

UNIT U   COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT V   COMPONENT

Power Booster, Burr-Brown 3329/03

UNIT W   COMPONENT

Power Booster, Burr-Brown 3329/03

UNIT X   COMPONENT CARRIER

X-2 to X-35	R14	300 ohm 1/4 watt
X-4 to X-33	R21	300 ohm, 1/4 watt
X-6 to X-31	R25	10 k, 1/4 watt
X-8 to X-29	R24	20 k, 1/4 watt
X-10 to X-27	R27	10 k, 1/4 watt
X-12 to X-25	R26	20 k, 1/4 watt
X-16 to X-21	R22	18 k, 1/4 watt
X-18 to X-19	R23	18 k, 1/4 watt

UNIT Y   COMPONENT

Operational Amplifier, Fairchild UA741DM

UNIT Z   COMPONENT

Comparator, National Semiconductor LM111

UNIT AA   COMPONENT

Comparator, National Semiconductor LM111

PARTS LIST FOR ELECTRONICS UNIT, BOARD 3

UNIT A **BUSS**

A-1 thru A-8 and A-14 thru A-16	Analog Common
A-9 thru A-12	+5 volts

UNIT B **BUSS**

B-1 thru B-8	+15 volts
B-9 thru B-16	-15 volts

UNIT C **COMPONENT**

Comparator, National Semiconductor LM111

UNIT D **COMPONENT**

Operational Amplifier, Burr-Brown 3500

UNIT E **COMPONENT**

Comparator, National Semiconductor LM111

UNIT F **COMPONENT CARRIER**

F-2 to F-23	C1	2.2 μF, 25 volt
F-4 to F-21	R1	1 k, 1/4 watt
F-6 to F-19	R4	100 k, 1/4 watt
F-8 to F-17	R5	12 k, 1/4 watt
F-10 to F-15	R3	10 k, 1/4 watt
F-12 to F-13	C2	15 μF, 20 volt Tantalex

UNIT G **COMPONENT CARRIER**

G-2 to G-23	D2	1N4532
G-4 to G-21	D3	1N4532
G-6 to G-19	R6	12 k, 1/4 watt
G-8 to G-17	R7	5.1 meg, 1/4 watt
G-10 to G-15	C3	0.0012 μF, 100 volt
G-12 to G-13	R9	510 ohm, 1/4 watt

UNIT H **COMPONENT CARRIER**

H-2 to H-23	R8	30 k, 1/4 watt
H-4 to H-21	D4	1N4532
H-12 to H-13	R10	1 k, 1/4 watt

PARTS LIST FOR ELECTRONICS UNIT, BOARD 3 (cont.)

UNIT J COMPONENT

Operational Amplifier, Burr-Brown 3500

UNIT K COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

UNIT L COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

UNIT M COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

UNIT N COMPONENT CARRIER

N-2 to N-23	R21	10 k, 1/4 watt
N-4 to N-21	R22	10 k, 1/4 watt
N-6 to N-19	R23	5.1 k, 1/4 watt
N-8 to N-17	R24	1.1 k, 1/4 watt
N-10 to N-15	R25	1.1 k, 1/4 watt

UNIT P COMPONENT CARRIER

P-2 to P-23	C5	15 μF, 20 volt Tantalex
P-4 to P-21	R16	1.8 k, 1/4 watt
P-6 to P-19	R15	2 k, 1/4 watt
P-8 to P-17	D1	1N4532
P-10 to P-15	R2	5.1 k, 1/4 watt
P-12 to P-13	C8	15 μF, 20 volt Tantalex

UNIT R COMPONENT CARRIER

R-2 to R-23	C4	2.2 μF, 25 volt
R-4 to R-21	D5	1N4532
R-6 to R-19	R11	51 k, 1/4 watt
R-8 to R-17	R12	39 k, 1/4 watt
R-10 to R-15	R13	22 k, 1/4 watt
R-12 to R-13	R14	200 k, 1/4 watt

UNIT S COMPONENT

Operational Amplifier, Fairchild UA741DM

PARTS LIST FOR ELECTRONICS UNIT, BOARD 3 (cont.)

UNIT T COMPONENT CARRIER

T-2 to T-23	R26	68 k, 1/4 watt
T-4 to T-21	C9	0.15 µF, 50 volt
T-6 to T-19	R27	68 k, 1/4 watt
T-8 to T-17	C10	0.15 µF, 50 volt

UNIT U COMPONENT

Quad Operational Amplifier, Motorola MC3503L

UNIT V COMPONENT CARRIER

V-2 to V-23	Z1	1N758
V-4 to V-21	R17	3 k, 1/4 watt
V-6 to V-19	R18	1 meg, 1/4 watt
V-8 to V-17	D7	1N4532
V-10 to V-15	C6	15 µF, 20 volt Tantalex
V-12 to V-13	C7	15 µF, 20 volt Tantalex

UNIT W COMPONENT CARRIER

W-2 to W-23	R20	9.1 k, 1/4 watt
W-4 to W-21	R19	2.7 k, 1/4 watt
W-6 to W-19	D6	1N4532

UNIT X COMPONENT

Hex Inverter, Texas Instruments SN5404J

UNIT Y COMPONENT

Quad Analog Switch, National Semiconductor AH0015CD

UNIT Z COMPONENT

Operational Amplifier, Fairchild UA741DM

PARTS LIST FOR ELECTRONICS UNIT, BOARD 4

UNIT A BUSS

A-1 thru A-8 and A-14 thru A-16	Analog Common
A-9 thru A-12	+5 volts

UNIT B BUSS

B-1 thru B-8	+15 volts
B-9 thru B-16	-15 volts

UNIT C COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

UNIT D COMPONENT CARRIER

D-2 to D-35	R1	100 k, 1/4 watt
D-4 to D-33	R2	30 k, 1/4 watt
D-6 to D-31	C1	15 µF, 20 volt Tantalex
D-8 to D-29	C2	15 µF, 20 volt Tantalex
D-10 to D-27	R3	100 k, 1/4 watt
D-14 to D-23	R5	5.1 meg, 1/4 watt
D-16 to D-21	R6	100 k, 1/4 watt
D-18 to D-19	R4	51 k, 1/4 watt

UNIT E COMPONENT CARRIER

E-2 to E-35	C3	15 µF, 20 volt Tantalex
E-4 to E-33	C4	15 µF, 20 volt Tantalex
E-6 to E-31	R7	15 k, 1/4 watt
E-8 to E-29	R8	51 k, 1/4 watt
E-10 to E-27	R9	12 k, 1/4 watt

UNIT F COMPONENT

Operational Amplifier, Fairchild UA741DM

UNIT G COMPONENT

FET Operational Amplifier, RCA CA3140S

UNIT H COMPONENT

Operational Amplifier, Fairchild UA741DM

UNIT J COMPONENT CARRIER

J-2 to J-35	R10	100 k, 1/4 watt
J-4 to J-33	R11	3 k, 1/4 watt

PARTS LIST FOR ELECTRONICS UNIT, BOARD 4 (cont.)

UNIT J COMPONENT CARRIER

J-6 to J-31	C5	15 µF, 20 volt Tantalex
J-8 to J-29	C6	15 µF, 20 volt Tantalex
J-10 to J-27	R12	100 k, 1/4 watt
J-14 to J-23	R14	5.1 meg, 1/4 watt
J-16 to J-21	R15	100 k, 1/4 watt
J-18 to J-19	R13	51 k, 1/4 watt

UNIT K COMPONENT CARRIER

K-2 to K-35	C7	15 µF, 20 volt Tantalex
K-4 to K-33	C8	15 µF, 20 volt Tantalex
K-6 to K-31	R16	15 k, 1/4 watt
K-8 to K-29	R17	51 k, 1/4 watt
K-10 to K-27	R18	12 k, 1/4 watt

UNIT L COMPONENT

Operational Amplifier, Fairchild UA741DM

UNIT M COMPONENT

FET Operational Amplifier, RCA CA3140S

UNIT N COMPONENT

Operational Amplifier, Fairchild UA741DM

UNIT P COMPONENT

Dual Analog Switch, National Semiconductor AH0014CD

APPENDIX C

Commercial Components

Unit	Description
Photomultiplier	ITT, Electro-Optical Products Division, Model FW130
High Voltage Power Supply	ITT, Industrial Laboratories Division, Model IL-3-1800
Torque Motor (2)	Inland, Model T-5135-D
Encoder (3)	Litton, Model 76NB10-3-S-1
Power Amplifier (2)	Control Technology, Model 987-3
Inverter	Abbott, Model S6D-115A-400, Output 115 v AC at 0.522 Amps, Input Range 24 to 30 v DC
DC-DC Converter	Abbott, Model BL2D-5A, Output 5 v at 4 Amps, Input Range 24 to 30 v
Cirkitblock Quad DC-DC Regulated Power Supply	Powercube Corporation, Model 28P5AB15CD
Filter	UTC Model LMI-200, Low-Pass Filter, 200 Hz Cutoff Frequency

Unit	Description
Motors:	
M1, Elevation Drive	Globe, Model 168A232-5, 27 v
M2, Azimuth Search	Globe, Model 168A102-5, 27 v
M3, Fast Azimuth Increase/Decrease	Globe, Model 168A159, 27 v
M4, Slow Azimuth Increase/Decrease	Globe, Model 168A-206-5, 27 v
Potentiometer	Spectrol, Model 200-8095, 10 Kilohms Linearity 0.3%
Potentiometer	Accuracy, Model P32, Resistance 9 Kilohms
Synchro Transmitter (2)	U.S. Navy, Type 15CX4a, MK 22, Mod 1
Synchro Control Transformer (2)	U.S. Navy, Type 15CT-4a, MK 14, Mod 1

8